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(54) Method of driving active-matrix liquid crystal display device.

(57) A method of driving an active-matrix liquid-crystal display device including switching elements connected to scan lines and data lines, and pixel electrodes for applying an electric field to a liquid (1A, 2A, 1B, 2B) with the aid of the switching elements, the switching elements and the pixel electrodes being arrayed in a matrix, and the liquid crystal being composed of a liquid crystal with spontaneous polarization includes the steps of : applying the electric field to the liquid crystal through the switching elements and the pixel electrodes for a time shorter than a response time of the liquid crystal, thereby charging the liquid crystal to excite molecules thereof ; scanning the liquid crystal lying at the pixel electrodes corresponding to all the scan lines by applying the electrical field in linear sequential mode, thereby forming one imaging field ; forming one frame by combining a plurality of the imaging fields serially ; and providing as a result a plurality of tones with a displayed image.

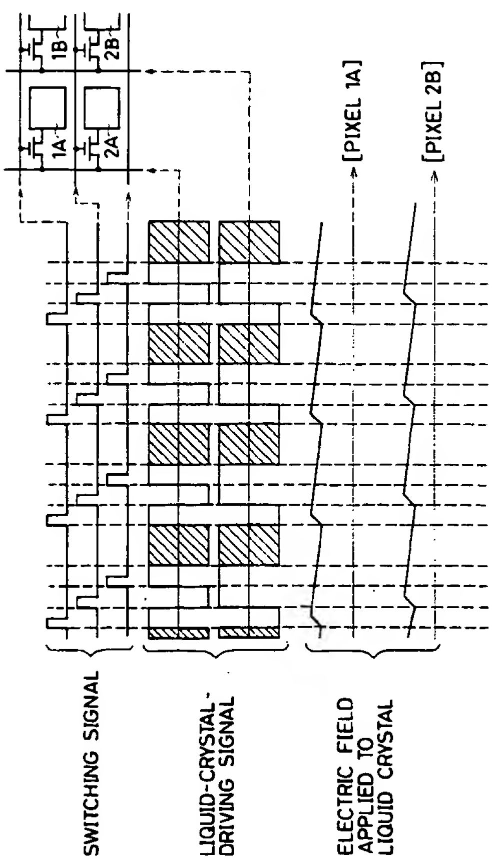

FIG.5

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BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method of driving an active-matrix liquid-crystal display device which is used as a liquid-crystal display device or a liquid-crystal-space-modulating device.

2. Description of the Related Art

As display modes using liquid crystals, there have conventionally been devised the DS (dynamic scattering) mode, TN (twisted nematic) mode, STN (supertwisted nematic) mode, ECB (electrically controlled birefringence) mode, PC (phase changel mode, memory mode, GH (guest-host) mode, and thermo-optical mode, which have been classified as such in accordance with their methods of converting electric signals applied to the liquid crystal to light information.

Among these display modes, the TN mode which mainly uses a nematic liquid crystal and the STN mode which is the improved TN mode are currently used for display devices in watches, electronic calculators, word processors, personal computers, televisions, and the like.

These modes utilize dielectric anisotropy and refractive-index anisotropy of molecules of the nematic liquid crystal as well as characteristics that directors of the molecules are moved by an electric field.

However, when a TN liquid-crystal device is driven in a multiplex address method, it is disadvantageous in that the drive margin of the device becomes narrow with the increase of the number of scanning lines, resulting in insufficient contrast. It is therefore difficult to fabricate a TN liquid-crystal device with a large display capacity.

To provide a large-capacity display with sufficient contrast for practical use, there have been proposed supertwisted nematic (STN) or supertwisted birefringence-effect (SBE) display devices and double-layer supertwisted nematic (DSTN) display devices, which are improved versions of the twisted nematic liquid-crystal display devices.

However, these display devices also have disadvantages such as low contrast or low response with the increase of the number of scanning lines.

In order to overcome the above-mentioned disadvantages of the nematic liquid crystals, an active-matrix liquid-crystal display device, which is obtained by combining with a conventional TN liquid-crystal and switching elements such as thin-film transistors (TFT) or MIM (metal-insulator-metal) elements arranged on a substrate, has been produced on an industrial basis and applied to televisions and other appliances which require high response speed.

This type of display devices cannot overcome the disadvantage of low response speed in the order of msec completely, because they are operated in principle in the field-effect mode which utilizes the dielectric anisotropy of liquid crystal molecules. That is, these display devices are not suitable for use, in particular, in CAD terminals or the like which require higher response speed.

In conventional liquid crystal displays with the TN or STN modes, including displays having active elements, visual-angle dependency with respect to the direction in which liquid-crystal molecules are twisted is unavoidable, in principle, because the electro-optic effect is obtained from a switching effect between the state in which twisted liquid-crystal molecules are homogeneously oriented and the state in which the molecules are erected on a substrate.

On the other hand, display devices using ferroelectric liquid crystals and anti-ferroelectric liquid crystals, the molecules of which have spontaneous polarization, have been proposed as liquid-crystal display devices with high response speed. The ferroelectric liquid-crystal display device (hereinafter referred to as FLCD) utilizes an electric interaction between a polarity resulting from the spontaneous polarization of the liquid crystal molecules and a polarity of an outer electric field so as to perform a switching action in accordance with the so-called conical movement of the molecules, thereby providing an extremely high-speed switching response (in the order of several μsec) compared with that of a device using nematic liquid crystals.

With the ferroelectric liquid crystals, several display modes which utilize the high-speed response of the ferroelectric liquid crystals and which are free of visual-angle dependency have been proposed and considered as promising liquid-crystal displays for the oncoming generation. These display modes include the one which uses the bistability of liquid crystals, such as a surface stabilized ferroelectric liquid crystal display (SSFLCD) proposed by N.A. Clark and Lagerwall (Appl. Phy. Lett., 36,899(1980); Japanese Unexamined Patent Publication No. 4355924; U.S. Patent No. (4367924), and the one which uses a scattering effect of liquid crystals, such as dynamic scattering mode.

These devices using the ferroelectric liquid crystals have such advantages as high-speed response and no visual-angle dependency over the conventional TN liquid-crystal display devices. However, they have several disadvantages to be overcome which are not seen in the TN liquid crystal display devices.

For example, the SSFLCD has three advantages of high-speed response (response time in the order of μsec), wide visual-field angle (resulting from the visual-angle characteristics of the polarizers), and bistability (holding a preceding state of orientation even after the intensity of the applied electric field is reduced to zero) over the TN and STN modes. However,

the display is also disadvantageous in that: it is extremely difficult to obtain the complete memory characteristics when a SSFLCD for practical use is fabricated by conventional liquid-crystal panel fabrication techniques only; contrast is reduced by the molecular movement which is caused by an electric field (bias electric field) applied to the liquid crystal during non-selective time of display operation, because there is no definite threshold for a switching action of the ferroelectric liquid-crystal molecules; and tonal display is difficult in principle because of the bistability. These disadvantages obstruct the development and application of the SSFLCD.

The disadvantages of the SSFLCD include all the disadvantages of other displays using the ferroelectric liquid crystals and using the anti-ferroelectric liquid crystals.

Some of the most serious disadvantages among them are caused by applying a bias electric field to the display. That is, when the display is driven in the simple multiplex address method, a variety of disadvantages are caused by the bias electric field (cross-talk electric field) as shown in Fig. 1 which is applied during a non-selective time (Fig. 1 shows electric fields applied to data lines and scan lines and electric fields applied to individual pixels of a liquid-crystal cell in the simple-matrix address method, wherein 1H represents a horizontal scanning time).

The following phenomena, which lead to the deterioration of display characteristics, may cause serious problems, though they slightly differ depending on the display mode being used:

(a) the deterioration of memory characteristics resulting from the movement of liquid-crystal molecules due to a bias electric field.

(b) the lowering of contrast resulting from light leak or unsatisfactory light shield caused by the movement of the molecules; and

(c) The level shift of tones due to the difference of bias waveforms applied.

With a conventional display using the ferroelectric liquid crystals or anti-ferroelectric liquid crystals, it is difficult to realize perfect tonal expressions on a liquid-crystal display for practical use, because the display mode, which utilizes as its display principle bistability of the liquid crystal or threshold characteristics of the liquid crystal with respect to the intensity of an applied electric field, cannot perform tonal display in principle or because the display mode which utilizes the transmittance or scattering intensity of light corresponding to the intensity of an applied electric field performs only limited tonal expressions which are clearly controllable, as described above with the problem caused by the bias electric field.

SUMMARY OF THE INVENTION

The present invention provides a method of driving an active-matrix liquid-crystal display device including switching elements connected to scan lines and data lines, and pixel electrodes for applying an electric field to a liquid crystal with the aid of the switching elements, the switching elements and the pixel electrodes being arrayed in a matrix, and the liquid crystal being composed of a liquid crystal with spontaneous polarization, comprising the steps of: applying the electric field to the liquid crystal through the switching devices and the pixel electrodes for a time shorter than an electro-optical response time of the liquid crystal, thereby charging the liquid crystal to excite molecules thereof; scanning the liquid crystal lying at the pixel electrodes corresponding to all the scan lines by applying the electrical field in linear sequential mode, thereby forming one imaging field; forming one frame by combining a plurality of the imaging fields serially; and providing as a result a plurality of tones with displayed image.

The imaging fields forming one frame each may be scanned during the same scanning time period.

The imaging fields may be scanned during different scanning time periods.

Further, the frame may comprise n units of fields to provide 2^n tones.

Preferably, the electrical field has such magnitude and polarity as to be cancelled during a time period for forming one frame.

The electrical field may have such magnitude and polarity as to be cancelled during a time period for forming a plurality of frames.

The method may further include the step of applying a high frequency alternative voltage having a cycle time shorter than the electro-optical response time of the liquid crystal to the liquid crystal for cancelling the applied electrical field.

A conventional ferroelectric liquid crystal or a conventional antiferroelectric liquid crystal may be used as the liquid crystal with spontaneous polarization.

Further, a liquid crystal material, for example, BDH-858 available from Merck Ltd., ALI-3654 available from Merck Ltd. or CS-1024 available from Chisso Corporation (Japan) is used as the ferroelectric liquid crystal.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a view illustrating electric fields applied to data lines and scan lines and electric fields applied to individual pixels of a liquid-crystal cell in the simple-matrix address method;

Fig. 2 is a waveform chart showing the characteristics of an active-matrix liquid-crystal display device with TFT devices;

Fig. 3 is a view showing the characteristics of a two-terminal switching device;

Fig. 4 is a waveform chart showing the character-

istics of an active-matrix liquid-crystal display device with two-terminal switching devices;

Fig. 5 is a waveform chart showing the electric fields applied to the data lines and scan lines, and the electric fields applied to the liquid crystal in the simple-matrix address method in accordance with the present invention;

Fig. 6 is a waveform chart showing a comparative example of the data-line and scan-line signals and the electric field applied to the liquid crystal in the matrix address method;

Fig. 7 is a waveform chart showing the data-line and scan-line signals and the electric field applied to the liquid crystal in the matrix address method in accordance with the present invention;

Fig. 8 is a waveform chart showing a comparative example of the data-line and scan-line signals and the electric field applied to the liquid crystal in the matrix address method;

Fig. 9 is a waveform chart showing the data-line and scan-line signals and the electric field applied to the liquid crystal in the matrix address method in accordance with the present invention;

Fig. 10 is a waveform chart showing the data-line and scan-line signals and the electric field applied to the liquid crystal in the matrix address method in accordance with the present invention;

Fig. 11 is a waveform chart showing the data-line and scan-line signals and the variation in quantity of light for illuminating the liquid-crystal cell in the matrix address method in accordance with the present invention;

Fig. 12 is a waveform chart showing the data-line and scan-line signals and the electric field applied to the liquid crystal in the matrix address method in accordance with the present invention;

Fig. 13 is a waveform chart showing the ideal method of varying the quantity of light from the light source when the variation in quantity of light from the light source is in synchronization with the scanning of switching devices;

Fig. 14 is a waveform chart showing the variation in intensity of light from a fluorescent tube when it is made to emit light in response to the pulse;

Fig. 15 is a waveform chart showing an example of the method of varying the quantity of light from the light source in accordance with the waveform of the pulse applied to the switching device of the liquid-crystal panel when the fluorescent tube is used for illuminating the liquid crystal;

Fig. 16 is a waveform chart showing the signal for driving an EL device and the variation in light intensity when the EL device is made to emit light;

Fig. 17 is a waveform chart showing the waveforms of applied pulses when 16 tones are displayed in which the electric field applied to the liquid crystal is not completely cancelled in accordance with the present invention;

Fig. 18 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed, along with Fig. 17, in accordance with the present invention;

Fig. 19 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed in accordance with the present invention;

Fig. 20 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed, along with Fig. 19, in accordance with the present invention;

Fig. 21 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed in accordance with the present invention;

Fig. 22 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed, along with Fig. 21, in accordance with the present invention;

Fig. 23 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed in accordance with the present invention;

Fig. 24 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed, along with Fig. 23, in accordance with the present invention;

Fig. 25 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed in which the electric field applied to the liquid crystal is not completely cancelled in accordance with the present invention;

Fig. 26 is a waveform chart showing the waveforms of the applied pulses when the 16 tones are displayed in which the electric field applied to the liquid crystal is not completely cancelled , along with Fig. 25, in accordance with the present invention;

Fig. 27 is a cross sectional view showing the constitution of the liquid-crystal cell;

Fig. 28 is a circuit diagram of a complex device of the switching device and the liquid-crystal cell using a sample-and-hold circuit, which is substantially equal to the device composed of the switching device and the liquid-crystal cell;

Fig. 29 is a waveform chart diagrammatically showing the variation in voltage of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28;

Fig. 30 is a waveform chart showing the waveforms of the pulses applied to the circuit shown in Fig. 28, the current passing through the liquid-crystal cell, and optical response when the liquid crystal is turned from OFF to ON;

Fig. 31 is a waveform chart showing the waveforms of the pulses applied to the circuit shown

in Fig. 28, the current passing through the liquid-crystal cell, and optical response when the liquid crystal is turned from ON to OFF;
Fig. 32 is a graph characteristically showing the variation in light transmittance of the cell in response to the switching signal when the electric field is applied to the liquid-crystal cell in accordance with the waveforms shown in Fig. 29;
Fig. 33 is a graph characteristically showing the variation in light transmittance of the cell in response to the switching signal when the electric field is applied to the liquid-crystal cell in accordance with the waveforms shown in Fig. 29;
Fig. 34 is a graph characteristically showing the variation in light transmittance of the cell in response to the switching signal when the electric field is applied to the liquid-crystal cell in accordance with the waveforms shown in Fig. 29;
Fig. 35 is a waveform chart showing the electric field applied to the liquid crystal and the response of the liquid-crystal cell when the liquid-crystal-driving signal is solely applied to the liquid-crystal cell;
Fig. 36 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 35;
Fig. 37 is a waveform chart diagrammatically showing the variation in voltage of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28;
Fig. 38 is a graph characteristically showing the variation in light transmitance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 37;
Fig. 39 is a waveform chart diagrammatically showing the variation in voltage of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28;
Fig. 40 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 39;
Fig. 41 is a waveform chart diagrammatically showing the variation in voltage of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28;
Fig. 42 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 39;
Fig. 43 is a waveform chart diagrammatically showing the variation in voltage of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28 in accordance with the waveforms in which display time equals to non-display time in length;
Fig. 44 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 43;
Fig. 45 is a waveform chart diagrammatically showing the variation in voltage of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28 in accordance with the waveforms in which the display time equals to the non-display time in length and high-frequency waves are superposed during the non-display time;
Fig. 46 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 45;
Fig. 47 is a waveform chart diagrammatically showing the variation in voltage of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28 in accordance with the waveforms with which the non-display time becomes shorter than the display time;
Fig. 48 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 47;
Fig. 49 is a waveform chart diagrammatically showing the waveforms of the switching signal and liquid-crystal-driving signal for each tone which are applied to the circuit of Fig. 28 so as to display four tones without canceling the electric field applied to the liquid crystal;
Fig. 50 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 49;
Fig. 51 is a waveform chart diagrammatically showing the waveforms of the switching signal and liquid-crystal-driving signal for each tone which are applied to the circuit in Fig. 28 so as to display the four tones in such a manner that the electric field applied to the liquid crystal is cancelled;
Fig. 52 is a graph characteristically showing the variation in light transmittance of the liquid-crys-

tal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 51;

Fig. 53 is a waveform chart diagrammatically showing the switching signal and liquid-crystal-driving signal applied to the circuit of Fig. 28 and the variation in intensity of light from the light source so as to display the four tones by varying the intensity of light for illuminating the liquid crystal in synchronization with the pulses applied to the liquid-crystal panel;

Fig. 54 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 53;

Fig. 55 is a cross sectional view of a typical TFT device;

Fig. 56 is another cross sectional view of the typical TFT device;

Fig. 57 is a perspective view of the typical TFT device;

Fig. 58 shows the waveforms of the signals applied to the gate, source, and common terminals of the TFT panel and of the electric field applied to the liquid crystal when high-frequency waves are superposed during the non-display time;

Fig. 59 shows the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 58;

Fig. 60 is a waveform chart showing the waveforms of the signals applied to the gate, source, and common terminals of the TFT panel and of the electric field applied to the liquid crystal when the non-display time is shorter than the display time;

Fig. 61 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 60;

Fig. 62 is a waveform chart diagrammatically showing the waveforms of the switching signal and the liquid-crystal-driving signal applied to the gate, source, and common electrodes of the TFT panel for each tone so as to display four tones without canceling the electric field applied to the liquid crystal;

Fig. 63 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 62;

Fig. 64 is a waveform chart diagrammatically showing the waveforms of the switching signal and the liquid-crystal-driving signal applied to the gate, source, and common electrodes of the TFT panel for each tone so as to display the four tones in such a manner that the electric field applied to the liquid crystal is canceled;

Fig. 65 is a graph characteristically showing the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 64; and

Fig. 66 is an equivalent circuit diagram of the active-matrix liquid-crystal display device in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A liquid-crystal display device according to the present invention is constituted so that: a pair of substrates are opposed to each other; pixel electrodes are arranged in a matrix on one substrate; each pixel electrode is provided with a switching device; a liquid crystal with spontaneous polarization such as a ferroelectric liquid crystal or an anti-ferroelectric liquid crystal is interposed between the substrates; an electric field can be applied to the liquid crystal via the switching device, between the pixel electrodes and the counter electrode; and the liquid crystal with spontaneous polarization is used in an operational mode having at least ON and OFF states and stably exhibits the ON or OFF states on condition that the intensity of the electric field is at a specified positive or negative value or more or that the intensity of the electric field is zero.

In the aforesaid liquid-crystal display device, the liquid crystal is driven by a driving method which has the characteristics described below.

To display one frame, the driving method is constituted so that: one frame is periodically rewritten; one frame is formed by scanning the switching devices corresponding to the frame one or more times; all the switching devices are scanned in accordance with a specified scanning unit such as every one device or every one scanning line; and the time needed for one-time scanning is constant or varies depending on a period during which frames are rewritten.

Pulses applied to the liquid crystal are characterized in that: the switching device can be driven by a pulse having a pulse width shorter than the electro-optical response time of the liquid crystal; a voltage applied to the liquid crystal in an ON state of the switching device is held by every pixel electrode when the switching device proceeds from the ON state to the OFF state; driving is so performed that when all the switching devices are scanned a plurality of times to form one frame, the ON or OFF state of the liquid crystal is switched by every scanning and so the ON and OFF states of the liquid crystal are alternately combined among the time axis; average intensity of

the electric field applied to the liquid crystal during the time for displaying one frame is not necessarily zero; when scanning is conducted a plurality of times to display one frame, pulses which are applied to the liquid crystal of one pixel for each scanning are roughly divided into a pulse for turning the liquid crystal ON, a pulse for turning the liquid crystal OFF, and a pulse for cancelling the electric field applied to the cell; the pulse for turning the liquid crystal ON or OFF and the pulse for canceling the electric field applied to the cell are not applied during the same scanning time; high-frequency waveforms are not superposed during the scanning time period in which the pulse for turning the liquid crystal ON or OFF is applied, while high-frequency waveforms are superposed during the scanning time in which the pulse for cancelling the electric charge of the ON or OFF state is applied; and each of the pulses for turning the liquid crystal ON and OFF has a constant wave-height and the pulse for cancelling the electric field applied to the cell has a wave-height which corresponds to an ON-OFF pattern of the liquid crystal of each pixel within the time for displaying one frame.

A light source for the liquid-crystal display device can be constituted so that: when the light intensity varies, it is possible to synchronize the period at which the light intensity varies with the period at which the switching devices of the liquid-crystal display device are scanned and to change the brightness for every scanning; the light intensity can be considered apparently constant on the condition that the period at which the light intensity changes is not in synchronization with the period during which the switching devices are scanned; or the light intensity is constant.

The aforesaid device constitution and drive method provide high-resolution display which enables high-speed rewriting, or the ON-OFF combination of the liquid crystal provides multi-tonal display. Figs. 66(a) and (b) show an equivalent circuit when the liquid-crystal display device is driven in the matrix address method in accordance with the present invention. In the drawings, an electric field is applied to a liquid crystal LC of each of pixels arranged in a matrix via a three-terminal or two-terminal switching device S or P.

A device which allows the passage of current in its ON state and which is in high impedance in its OFF state can be used for the switching device S or P. For example, a device such as a thin-film transistor (TFT) as shown in Fig. 2, which applies an electric field to the liquid crystal in its ON state and which is in high electric impedance in its OFF state, or a device such as a diode, MIM, or varistor as shown in Fig. 3 which allows the passage of electric current with a voltage of a specified value or more and which is in high impedance with a voltage of a lower value than the specified value.

An embodiment of the present invention with a liquid crystal cell constituted as above will be described.

it is confirmed that since a ferroelectric liquid crystal does not have a definite threshold for electro-optical switching as a nematic liquid crystal does, molecules of the liquid-crystal will even respond to the faintest electric field applied to them and make a conical movement to the position where a winding force of the liquid crystal to form a helix and an electric interaction between the dipole of the liquid-crystal molecules and the outer applied electric field are in equilibrium. It can be considered that this movement of the liquid-crystal molecules causes to lower display contrast.

An effect obtained by combining the switching device with the ferroelectric liquid crystal results from the following two states of the liquid-crystal cell in the non-selective state of operation.

(1) The liquid crystal is not charged by a bias electric field.

(2) The liquid crystal is in high electric impedance.

The phenomenon of (1) has the following effect.

In an ordinary simple-matrix address method, even if a given pixel is in a non-selective state, a signal for rewriting another pixel is constantly applied to a data line. Liquid-crystal molecules move due to the resulting electric field, namely, the bias electric field (Fig. 1), thus causing a phenomena which lead to lowering of contrast and deterioration of memory characteristics.

However, the signal for driving another pixel is not applied to the pixel with the provision of a switching device, provided that the switching device is in the OFF state as shown in Fig. 2 (three-terminal non-linear device) and in Fig. 4 (two-terminal non-linear device). Consequently, the lowering of contrast and the deterioration of memory characteristics which are caused by the bias electric field applied in the simple-matrix address method can be prevented, because the liquid-crystal molecules do not move in the non-selective time, resulting in the improved contrast and quality of display images. Fig. 2 diagrammatically shows the characteristics of a TFT device, wherein the electric fields of a scan signal and a data signal applied to gate and source terminals of the TFT, respectively, and an electric field applied to the liquid crystal via the drain terminal of the TFT are shown.

Fig. 3 diagrammatically shows the characteristics of a two-terminal switching device.

Fig. 4 diagrammatically shows signals applied to the data line and to the scan line, and an electric field being applied to the liquid crystal when two-terminal switching devices are used. A signal designated as SCAN SIGNAL in the drawing is applied to the scan line and a signal designated as DATA SIGNAL in the drawing is applied to the data signal.

When the switching device is turned from ON to

OFF, the electric field applied to the liquid crystal is partly held by the capacitor component of the liquid-crystal cell in accordance with the phenomenon of (2).

This electric field held in the OFF state of the switching device holds the liquid-crystal molecules in a position (wherein the polarization of the liquid-crystal molecules, the outer electric field being held, the winding force of the liquid crystal to form a helix and the like are in equilibrium), which is different from the position of the molecules when the intensity of the electric field is zero.

If one display condition is composed of the state in which the liquid-crystal molecules are in equilibrium due to the electric field held in the OFF state of the switching device and the other display condition is composed of the state in which the direction of the electric field being held is reverse or the intensity of the electric field being held is zero, the ON time of the switching device can satisfactorily be reduced to a time required only for applying the electric field so as to switch the liquid crystal within the period from a driven ON state to the next ON state of the switching device.

This leads to reducing the pulse with of a voltage for operating the switching device and to lowering the magnitude of a voltage applied to the liquid crystal.

However, since electric current flows inside the liquid crystal cell where the spontaneous polarization of the liquid-crystal molecules moves, there occurs a phenomenon of discharging the electric field which was held by the capacitor component of the cell. Hence, strictly speaking, the electric field necessary to switch the liquid crystal should be sufficiently large to compensate for the electric field discharged when the liquid crystal is switched as well as hold the state of the liquid crystal.

Also, it is not necessary to charge the liquid crystal and its capacitor up to 90% of the voltage of the electric field, as with an ordinary TN liquid crystal, since the electric field required for switching ferroelectric liquid-crystal molecules is small. Therefore, the present invention is sufficiently applicable to existing switching devices such as TFT and MIM. For example, it is possible to perform the switching operation of the liquid-crystal molecules with the gate width of 10 μsec or less even in an a-Si TFT device, which requires the gate width of 15 μsec or more with the TN liquid crystal.

It is also effective to reduce the width itself of the pulse for operating the switching device in realizing: the increase of the number of switching devices per frame which can be driven; the increase of the number of times of scanning for displaying one frame (the number of fields per frame); the increase of the frame frequency; and the reduction of consumption power.

Of these effects, the increase of the number of the switching devices per frame which can be driven suggests that display capacity is increased, the increase of the number of times of scanning (field number of times) suggests that the electric field applied to the liquid crystal can be transformed to alternating current by selectively combining a variety of waveforms for application and that tonal display can be performed by time-sharing addressing, and the increase of the frame frequency suggests that the quality of display images is improved.

Moreover, since the direct-current component applied to the liquid crystal is reduced because of the lowered voltage of the switching pulse for the liquid crystal, the influence on the liquid crystal even when the liquid crystal is driven by a non-dipolar pulse is small compared with the case in which the ferroelectric liquid crystal is driven by the simple-matrix address method.

By utilizing the low-power driving resulting from the combination of the foregoing switching device and the liquid crystal with spontaneous polarization and the increase of the number of times of scanning for displaying one frame, a novel display method in accordance with the present invention, that is, tonal display with high contrast by driving with a plurality of successive pulses having the same polarity can be realized.

Next, the display principle by the novel method will be described below.

The active-matrix addressing of the liquid crystal in the following description is performed in accordance with the method using a three-terminal switching device shown in Fig. 66(a). The scan-line signal applied to the gate terminal so as to turn the switching device ON or OFF via the scan line is used as the switching signal and the data-line signal applied from the data line to the liquid crystal via the source terminal and drain terminal of the switching device S is used as the liquid-crystal-driving signal.

Monochrome Display

The waveforms shown in Figs. 5 to 9 are for performing monochrome display.

In Fig. 5, the liquid crystal is constantly charged with the direct-current component because the switching device is turned OFF when the intensity of the electric field applied to the liquid crystal is not zero. In the drawings, the regions hatched with oblique lines designate a region in which the electric field is indefinite because the switching state of the liquid crystal is not defined. This case is characterized in that the data-line signal is held in the fall time of the scan-line signal and that a waveform which cancels the electric field applied to the liquid crystal is not applied.

In Fig. 6, the switching signal is turned OFF after the intensity of the electric field applied to the liquid crystal becomes zero so that the liquid crystal is

charged with the electric field only when the pulse is applied. This case is characterized in that the data-line signal is zero in the fall time of the scan-line signal and that a waveform for cancelling the electric field applied to the liquid crystal is not applied.

In Fig. 7, the liquid crystal is constantly charged with the direct-current component because the switching device is turned OFF when the intensity of the electric field applied to the liquid crystal is not zero. However, since the electric field in time of the first scanning and the electric field in time of the second scanning are in the opposite directions, the direct-current component which is applied to the liquid crystal on the whole is only the electric-field component which is applied to the liquid crystal during the interval between the first scanning time and the second scanning time. This case is characterized in that the data-line signal is held in the fall time of the scan-line signal and that a waveform with the reverse phase of that of the display waveform is applied to the liquid crystal so as to cancel the electric field.

In Fig. 8, the switching signal is turned OFF after the intensity of the electric field applied to the liquid crystal becomes zero so that the liquid crystal is charged with the electric field only when the pulse is applied. Since the electric field in time of the first scanning and the electric field in time of the second scanning are in the opposite directions, the direct-current component which is applied to the liquid crystal is cancelled on the whole. This case is characterized in that the data-line signal is zero in the fall time of the scan-line signal and that a waveform with the reverse phase of that of the display waveform is applies to the liquid crystal so as to cancel the electric field.

In Fig. 9, the liquid crystal is constantly charged with the direct-current component because the switching device is turned OFF when the intensity of the electric field applied to the liquid crystal is not zero. However, since the electric field in the first scanning and the electric field in the second scanning are in the opposite directions and since the intensity of the electric field is zero during the scanning times from the third scanning on, the direct-current component applied to the liquid crystal is canceled on the whole. In this case, however, it is required during the scanning times from the third scanning on that the liquid crystal is in the memory state in which the liquid crystal is not switched from ON to OFF and from OFF to ON, in the metastable state, or in the slow relaxation process. This case is characterized in that the data-line signal is held in the fail time of the scan-line signal and that a waveform with the reverse phase of that of the display waveform is applied so as to cancel the electric field applied to the liquid crystal and then the switching device is operated so as to reduce the intensity of the electric field to zero.

The display condition of the liquid crystal while it is held with no electric field is for displaying information to be recognized by human beings, and it is required to hold the display condition so that it is at least recognizable within the range of human recognition. This display condition is in the memory state or in the transient state of the relaxation process in accordance with the electric field applied immediately before the intensity thereof becomes zero.

In Figs. 5, 7, and 9, the time for turning the switching device ON is shorter than those of other waveforms, because the switching of the liquid crystal is sufficiently completed within the period of one field. As a result, the intensity of the electric field applied to the liquid crystal may be small.

The waveforms in Figs. 7, 8, and 9 show the scanning for displaying the reversed condition of the normal condition to be displayed. However, since human eyes cannot recognize high-speed blinks of 1/10 sec or less and can only recognize as brightness the time-averaged variation in brightness caused by blinks, the objective display condition can be recognized by human eyes when the scanning time for the objective display condition and the scanning time during which the objective display condition is held (this time is designated as display time) are set longer than the scanning time for displaying the reverse of the objective display condition (this time is designated as reverse display time). The difference in brightness in this case can be formulated as follows:

(Difference of Brightness by Human Visual Observation) = (Length of Display Time)x(Brightness in Display Time) - (Length of Non - display Time) x (Brightness in Non - display Time)

There are three practical display methods to differentiate the brightness in the display time from the brightness in the non-display time, which are shown below:

A. As shown in Fig. 10, the display time is set longer than the non-display time. The time for one-time scanning in the display time is set longer than the time for one-time scanning in the non-display time.

B. Scanning is performed in the display time more frequently than in the non-display time.

C. As shown in Fig. 11, the intensity of light from the light source for the liquid crystal is varied in synchronization with scanning, The light used in the display time is set intenser than the light used in the non-display time.

D. As shown in Fig. 12, a high-frequency component with which the liquid-crystal molecules cannot completely be switched is superposed on the electric field applied to the liquid crystal during the non-display time. As a result, the liquid-crystal molecules are substantially held in the state of the display time.

Fig. 10 is characterized in that the data-line signal is held in the fall time of the scan-line signal, a dis-

play waveform for canceling the electric field applied to the liquid crystal is applied, and the non-display time is shorter than the display time.

Fig. 11 shows the data-line signal, the scan-line signal, and the variation in quantity of light for illuminating the liquid-crystal cell when the matrix driving is performed, similarly in Fig. 5. In the drawing, the signals applied to the data line and the scan line, respectively, are the same as those in Fig. 10 in terms of the pulse applied to the liquid crystal. In addition to the characteristics of the waveforms of Fig. 10 with which the electric field is applied, this case is also characterized by the increase in quantity of light from the light source which was observed from the time when scanning of all the scan lines was completed till the beginning of the non-display time compared with other periods of time.

Fig. 12 is characterized in that the data-line was held in the fall time of the scan-line signal, that the display wave was applied so as to cancel the electric field applied to the liquid crystal, and that the high-frequency component was superposed on the liquid crystal during the non-display time.

If these waveforms on which high-frequency waves are superposed are to be applied to the liquid crystal with the switching device of TFT, a waveform in which the high-frequency wave is superposed on the counter electrode of TFT during the non-display time is applied. In case that a two-terminal switching device is used as the switching device, a waveform is composed so as to superpose the high-frequency wave on the data-line signal during the non-display time. It is necessary that the amplitude of the high-frequency component then applied fulfills a requirement represented by a following inequality.

$$V_O < V_D - V_{hf}$$

In the methods shown in A and B, the difference in length between the display time and the non-display time leads to the average brightness sensed by human eyes.

In the method shown in C, the difference in intensity of light from the light source between the display time and the non-display time is sensed as brightness by human eyes. Therefore, the relationship between the variation in intensity of light from the light-source device and the time needed for scanning each switching device is closely related to the display characteristics. It is ideal that the light source used in this method exhibits the light-intensity characteristics shown in Fig. 13 with respect to scanning. In practice, however, light-source devices which emit light in response to pulses so that the light intensity attenuates thereafter are used for the liquid crystal. Representatives of these devices are an incandescent lamp, a fluorescent lamp, and an electroluminescent (EL) lamp, with which the light intensity varies in response to an effective value applied. In the present embodiment, a fluorescent lamp or an EL lamp which responds to pulses is appropriate for the light source, because the scanning time lasts only several msec.

When a fluorescent lamp is used, the light intensity varies in response to the pulse applied for lighting as shown in Fig. 14. In the ordinary liquid-crystal display, a fluorescent tube is lit by high-frequency pulses so as to eliminate flickers. In the present invention, a method for varying the light intensity can be devised, in which a pulse for lighting the fluorescent tube is applied in the display time while the pulse for lighting the fluorescent tube is not generated in the non-display time. It is also possible in practice to adopt a method in which different brightnesses are provided in the display time and in the non-display time by changing brightness depending on the number of pulses to be sent for lightning during the scanning time, so as to realize the stepwise variation in brightness. When the electroluminescent (EL) lamp is used, light intensity varies in response to the pulse applied for lighting as shown in Fig. 16. In this case also, the EL lamp can be driven in the same manner as the fluorescent tube, as shown in Fig. 15.

In the method shown in D, when a liquid-crystal material with a negative E is used in a display mode in which positive and negative pulses stand for the turning ON and OFF of the display (SSFLC, for example), the stabilizing effect is produced by superposing the high-frequency component or the liquid-crystal material, so that switching does not readily occur. As a result, the variation in intensity of the transmitted light between the ON state and the OFF state becomes small, due to the incomplete switching of the ferroelectric liquid-crystal molecules. When a liquid-crystal material with a positive E is used, leakage or scattering of light is incurred by the constant movement of liquid-crystal molecules because the high-frequency component causes the perturbation motion of the liquid-crystal molecule centering around the stable position of the vertical cone along which the liquid-crystal molecule moves. Because of the light leaked and scattered, the variation in intensity of the transmitted light in this case accordingly becomes smaller than the variation in intensity of the transmitted light in the ON and OFF states in which the high-frequency component is not superposed. Though the cause differs whether the liquid-crystal material has the positive E or the negative E, as described above, it is also possible to prevent the lowering of contrast of display because the variation in intensity of transmitted light of the non-display rime is smaller than that of the display time.

In order to provide display with higher contrast in practice, it is effective to constitute the device by using a combination of the three methods described above.

Tonal Display

According to the present method, it is also possible to provide tonal display by the time-sharing method. That is, one pixel for display is turned ON or OFF by every scanning so that the ON-OFF pattern of a plurality of fields which compose one frame enables tonal display.

However, the present drive method requires waveforms different from those of the simple-matrix address method, as shown in Fig. 1, because the liquid crystal is driven by applying more pulses with the same polarity in succession. Examples of the waveform are shown in Figs. 17 and 18.

Although it is not clear from the waveforms shown in the drawings that the signal for driving the ferroelectric liquid crystal is OV or not at the trailing edge of the switching signal from ON to OFF, the clear-cut distinction is omitted because every condition displayed by the liquid crystal when the switching device is OFF is already determined by the liquid-crystal-driving signal which was applied when the switching device was ON. Figs. 17 and 18 show examples of the pattern of applied pulses when sixteen tones are displayed in the present method. The drawings show the waveform of the switching signal (gate pulse and source pulse) which is regularly applied. in this case, the tone 1 and the tone 2 are observed at the same luminance, but, if different waveforms are used for applying the switching signals, the sixteen tones can be obtained by utilizing the difference in time between the switching signals. The drawings are characterized in that the direct-current component applied to the liquid crystal in one frame is not cancelled and that the field scanning times for composing one frame are constant. If the period of displaying one frame is shortened in this method, it becomes difficult to differentiate the waveforms for applying the switching signals, sometimes with a result that only five out of the sixteen tones can substantially be recognized

By defining the conditions displayed by the liquid crystal to the two values of OR and OFF, even when an electric field with the intensity of a specified value or more is applied, it becomes possible to perform driving in which the direct-current component applied to the liquid crystal for driving the liquid crystal is canceled by utilizing the ON or OFF state of the liquid crystal, which are shown in Figs. 19 and 20.

Figs. 19 and 20 show the example of the waveforms of applied pulses when the sixteen tones are displayed in the present methods. The drawings are characterized in that one frame has one scanning time during which the pulse for cancelling the electric field applied to the liquid crystal is applied within the period for displaying one frame and that the scanning time composing one frame is constant. If the period of displaying one frame is shortened in this method, similarly in Figs. 17 and 18, there is also a possibility that only five out of sixteen tones can substantially be recognized.

When multi-tonal display is performed, the direct-current component applied to the cell during the display time is significantly biased, so that an extremely large pulse, compared with the pulse applied during the display time, may be required in order to completely cancel the direct-current component. However, if a large pulse is applied to the liquid crystal in this case, device characteristics incur a number of problems such as the significant change of the orientation.

In order to prevent these problems, a plurality of pulses are separately applied in several non-display times within the period of forming one frame, as shown in Figs. 21 and 22, instead of applying one large pulse in the single non-display time. Figs. 21 and 22 show an example of the waveforms of applied pulses when the sixteen tones are displayed in accordance with the present method. The drawings are characterized in that one frame has a scanning time during which several pulses for canceling the electric field applied to the liquid crystal are applied and that the electric field applied to the liquid crystal is canceled by the pulses within the period of displaying one frame.

A method can be proposed in which pulses are applied in the non-display time so as not to completely cancel the pulses which were applied in order to perform the display shown in Figs. 23 and 24 or in the Figs. 25 and 26. Figs. 23 and 24 show an example of the waveforms of applied pulses when the sixteen tones are displayed in accordance with the present method. The drawings are characterized in that one frame has only one scanning time during which pulses for cancelling a part of the electric field applied to the liquid crystal are applied.

Figs. 25 and 26 show an example of the waveforms of the applied pulses when the sixteen tones are displayed in case that the electric field applied to the liquid crystal is not completely canceled, similarly in Figs. 23 and 24. The drawings are characterized in that pulses for cancelling a part of the electric field applied to the liquid crystal, similarly in Figs. 23 and 24, are on the same level as that of the ON-OFF signals for the liquid crystal and that the positive or negative electric field is applied in accordance with the display pattern.

As described above, it is appreciated that the present drive method using the device constituted by a combination of the ferroelectric liquid crystal and the switching device in accordance with the present invention enables novel tonal display, which was not conventionally provided. The key to the tonal display by this drive method is described below in two items, which are: the prevention of the lowering of contrast due to the non-display pulse applied to the liquid

crystal; and the recognition as a tone of a time interval between high-speed blinks.

However, problems which arise when the two items are not obtained can be solved by extensively applying the solution described above to the monochrome display.

As for the problem concerning the first item, it can be overcome to some extent if the variation in light quantity resulting from the turning ON and OFF of the liquid crystal during the non-display time is set smaller than the variation in light quantity for one scale of tones during the display time.

As for the problem concerning the second item, each ON-OFF combination can be differentiated by changing the length of the scanning time or the intensity of light from the light source for each of several times of scanning. By differentiating the ON-OFF combination in every scanning time, for example, each of the four BITS required for displaying the sixteen tones can be used to turn a pixel ON or OFF in every scanning.

In case that more tones are displayed by this method, the maximum number of tones that can be displayed is determined depending on the number of times of field scanning for displaying one frame. That is, when the number of times of field scanning for displaying one frame (including the number of times of field scanning for cancelling the electric field) is represented by m and the number of times of field scanning for canceling the applied electric field is represented by n, the maximum number of tones that can be displayed is 2^{m-n}.

If the sum total of the intensity of light from the light source and the time within the period of displaying one frame, there occurs a phenomenon that the difference in pattern can be recognized visually but the difference in brightness cannot precisely be recognized (because only averaged brightness is recognized), so that the number of tones which can be used in practice is sometimes reduced. In particular, tones having the same brightness are produced due to the light loss resulting from the leakage, scattering, or absorption of light caused by pulses during the non-display time.

EXAMPLE 1

Fabrication of a liquid-crystal cell

A ferroelectric liquid-crystal cell (Fig. 27) with no switching device was fabricated in accordance with the following steps:

1. A plurality of transparent electrodes 2a and 2b with the thickness of 1000 Å were formed in parallel on glass substrates 1a and 1b by arranging patterns for the electrodes in stripes. The thickness of the transparent electrodes can be set in the range of 300 to 1500 Å, preferably 1000 to 3000 Å.

2. Electrode-protective films 3a and 3b were formed on the substrates obtained in the step 1 to the thickness of 1000 Å. The thickness of the electrode protective films can be set in the range of 300 to 5000 Å, preferably 500 to 2000 Å.

The electrode-protective films were formed from SiO_2 or OCD (OCD P-59310) available from Tokyo Ohka Kogyo Co., Ltd. The electrode-protective films of SiO_2 were formed by sputtering, while the electrode protective films of JCD were formed by coating OCD on the substrates by a spinner, followed by sintering.

3. Orientation films 4a and 4b were formed on the substrates obtained in the step 2 to the thickness or 400 Å. The orientation films were formed by applying such materials as PSI-X-A-2001 (polyimide) available from Chisso Corporation or RN715 available from Nissan Chemical Industries, Ltd. (Japan) with a spin coater, followed by sintering. The thickness of the orientation films can be set in the range of 200 to 1000 Å.

4. The substrates fabricated in the step 3 were subjected to uniaxial orientation treatment by rubbing techniques with the use of rayon-type cloth. In this case, rubbing was performed so that the substrates 1(a) and 1(b) would have the same rubbing direction when they are joined together with their electrode patterns at right angles.

5. Between the upper and lower substrates which have gone through the steps 1 to 4, silica beads with the diameter of 3.0 µm were dispersed so as to serve as spacers 6, and the substrates were joined with a sealing member 7 of epoxy resin.

6. The ferroelectric liquid-crystal composition 5 in accordance with the present invention was injected by vacuum injection techniques to the panel fabricated through the steps 1 to 5. After injection, the opening for injection was hermetically sealed with a UV-setting resin of acrylic type.

Driving of the Liquid-crystal Cell

In order to confirm the operational characteristics of the liquid-crystal cell fabricated above, an principle experiment was conducted with a sample-and-hold circuit on the basis of the operational principle of the switching device.

That is, the operational principle was confirmed by using the ON state of the switching device as the sampling state of the sample-and-hold circuit and the OFF state of the switching device as the hold state of the sample-and-hold circuit (hereinafter referred to as "hold state").

In the sample-and-hold circuit, the liquid-crystal cell was used as the hold capacitor.

The sample-and-hold circuit used here is constituted by the circuit shown in Fig. 28. Fig. 28 is a circuit

diagram of a complex device of the switching device and liquid-crystal cell using the sample-and-hold circuit which is substantially equivalent to a combined device of the switching device and liquid-crystal cell. In the present circuit, LF398 available from National Semiconductor was used as the sample-and-hold circuit. Hereinafter, sampling-source signals from the sample-and-hold circuit will be referred to as liquid-crystal-driving signals, sampling signals from the sample-and-hold circuit as switching signals, and the pulse width of the sampling signals as gate-pulse width.

The SSF ferroelectric liquid-crystal cell fabricated above was placed between polarizers at crossed nicols so that intensity variation of the transmitted light reach the maximum value on application of pulses. The change of the light transmittance intensity through the LC cell in response to the applied electric field was measured with a phototransistor. The switching of the liquid-crystal cell had been normalized by setting the maximum value of the intensity of the transmitted light at 1 and the minimum value of the intensity of transmitted light at 0 with the use of square waves (500 Hz) to which the liquid crystal responds.

As the light source for the system of measurement, an incandescent bulb which is driven by direct current was used.

Drive Experiment (1)

BDH-858 (available from Merck Ltd. Poole England) was used as the liquid-crystal material. The voltage applied to the liquid crystal when liquid-crystal-driving signals and switching signals were applied in accordance with the waveforms shown in Fig. 29, the intensity variation of the transmitted light on application of pulses producing the ON state, and the intensity variation of the transmitted light on application of pulses producing the OFF state are plotted in Figs. 30 and 31 (the wave-height value of the liquid-crystal signals is +5V). Fig. 29 diagrammatically shows the intensity variation of the electric field applied to the liquid crystal on application of the switching and liquid-crystal-driving signals to the circuit of Fig. 28.

Fig. 30 shows the waveforms of pulses applied to the circuit shown in Fig. 28, the current passing through the liquid-crystal cell and optical response when the liquid crystal is turned from OFF to ON.

Fig. 31 shows the waveforms of pulses applied to the circuit shown in Fig. 28, the current passing through the liquid-crystal cell and optical response when the liquid crystal is turned from ON to OFF.

In Fig. 32, the average intensity of the transmitted light in the ON and OFF states of the liquid crystal in the hold state is plotted when the pulse width of the switching signals was varied from 0.1 μsec to 1000 μsec and the wave-height value of the liquid-crystal-driving signals was +5V. Fig. 32 shows the variation in light transmittance of the liquid-crystal cell in response to the switching signals when the electric field is applied to the cell using BDH-858 as the liquid-crystal material in accordance with the waveforms shown in Fig. 29.

In Figs. 33 and 34, the average intensity of the transmitted light in the ON and OFF states of the liquid crystal in the hold state was plotted when the width of the switching signals in the circuit of the present experiment using ZLI-3654 (available from Merck Ltd. Poole England) and CS-1024 (available from Chisso Corporation) was varied from 0.1 μsec to 1000 μsec. Fig. 33 shows the variation in light transmittance of the liquid-crystal cell in response to the switching signal when the electric field is applied to the liquid-crystal cell using ZLI-3654 as the liquid-crystal material in accordance with the waveforms shown in Fig. 29.

Fig. 34 shows the light transmittance change of the liquid-crystal cell in response to the switching signals when the electric field is applied to the cell using CS-1024 as the liquid-crystal material in accordance with the waveforms shown in Fig. 29.

According to the experiment described above, the following matters were confirmed. In performing the switching of liquid-crystal molecules with spontaneous polarization, the electric field which was applied immediately before the switching was held because the pixel which was not electrically selected becomes open. With this effect, the time for applying the electric field to the liquid crystal shows that it is possible to cause the switching by applying a pulse having an extremely shorter width than the pulse width which is necessary to cause the electro-optical switching of the single liquid-crystal material itself in the conventional simple-matrix address method. However, it is required that the time needed for one time of scanning in this case is longer than the response time of the liquid crystal.

Comparative Example

The intensity variation of the light transmitted by the liquid-crystal cell was measured when the liquid-crystal-driving signal was solely applied to the ferroelectric liquid crystal. Fig. 36 shows the intensity variation of the electric field applied to the liquid crystal and the quantity variation of the light transmitted by the cell when the liquid-crystal-driving signal was solely applied to the liquid crystal cell by varying the pulse width of the gate signal.

That is, Fig. 36 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field was applied to the cell in accordance with the waveforms shown in Fig. 35.

Comparative Example

The variation in intensity of the transmitted light was measured when the pulse, to be applied to the liquid crystal, was applied in accordance with the waveforms shown in fig. 37 in which the pulse, prior to the sample-and-hold signal from the sample-and-hold circuit, becomes OV. That is, Fig. 37 shows the variation in voltage of the electric field which is applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28.

The light intensity transmitted by the liquid crystal was measured by using the gate signal having a different pulse width and plotted in Fig. 3b. That is, Fig. 38 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 37.

Comparative Example

By using a dipolar pulse as the pulse applied to the sample-and-hold circuit, the variation in intensity of the transmitted light was measured when the pulse, to be applied to the liquid crystal, was applied in accordance with the waveforms shown in Fig. 39 in wich the pulse, prior to the sample-and-hold signal from the sample-and-hold circuit, becomes 0V. Fig. 39 diagrammatically shows the electric field intensity applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28.

The intensity of light transmitted by the liquid crystal was measured by using the gate signal having a different pulse width and plotted in Fig. 40. That is, Fig. 40 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 38.

Each of the above comparative examples shows that the pulse width which is at least equal to the memory pulse width is required to electro-optical switching of the liquid crystal, because the electric field was not held.

Drive Experiment (2)

The change of light transmittance intensity was examined in the same manner as described above by applying the pulse having the waveform shown in the drawing to the sample-and-hold circuit.

Fig. 40 shows the light transmittance change of the liquid-crystal cell in response to the pulse having the waveform of Fig. 41 which was applied when the voltage of the liquid-crystal-driving signal is + 10V and the pulse width of the sampling signal in case of using BDH-858 (available from Merck Ltd. Poole England) as the liquid-crystal material was changed from 0.1 μsec to 1000 μsec. Fig. 41 diagrammatically shows the variation in intensity of the electric field applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28.

The four different hold states were produced by applying the pulse in accordance with the waveforms shown in the drawing when the light transmittance change in response to a square wave (500 Hz) to which the liquid crystal can respond with respect to the pulse width of the sampling signal of each liquid-crystal material is determined as 1. The four hold states are: (1) the hold state immediately after the pulse for producing the ON state of the liquid crystal is applied; (2) the hold state sampled at OV under the ON state of the liquid crystal; (3) the hold state immediately after the pulse for producing the OFF state of the liquid crystal is applied; and (4) the hold state sampled at OV under the OFF state of the liquid crystal. The light transmittance changes in these four hold states are plotted in Fig. 42. That is, Fig. 42 shows the light transmittance change in response to the switching signal from the initial ON state when the electric field is applied to the liquid-crystal cell in accordance with the waveforms shown in Fig. 39 with the electric field applied to the cell being held and the light transmittance change in response to the switching signal from the initial OFF state when the applied electric field becomes zero to provide the state of high impedance once again. The results of Fig. 42 confirmed the following matters.

In this case, the optical response is caused by the first liquid-crystal-driving signal and the electric field applied to the liquid crystal is discharged in the next operation of the switching device, thereby providing operation with the reduced direct-current component applied to the liquid crystal.

With the combination of TFT and SSFLCD, the one field time for scanning the ali switching devices making one screen can be shortened compared with that of SSFLCD of the simple matrix type.

Because the memory characteristics of the liquid crystal itself are utilized in the alignment of the liquid crystal used for display, the applied electric field can be decreased.

Comparative Example

The change of light transmittance intensity was examined in the same manner as described above by applying the pulse having the waveform of Fig. 43 to the sample-and-hold circuit.

The change of light transmittance intensity of the liquid crystal by using the gate signal with a different pulse width when the display time equals to the non-display time in length was examined and plotted in Fig. 44. That is, Fig. 43 diagrammatically shows the

electric field intensity when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28 in accordance with the pulse waveforms in which the display time equals to the non-display time, and Fig. 44 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 34. Fig. 44 shows that, because the display time equals to the non-display time in length, the light transmittance remains 50 % and so clear ON-OFF display is not obtained, though the optical response is observed, for the brightness of one frame is averaged.

Drive Experiment (3)

The change of light transmittance intensity was examined in the same manner as described above by applying the pulse having the waveform of fig. 43 to the sample-and-hold circuit.

The light transmittance intensity of the liquid crystal by using the gate signal with a different pulse width is plotted in Fig. 46. That is, Fig. 45 diagrammatically shows the electric field intensity applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28 in accordance with the pulse waveforms in which the display time equals to the non-display time in length and a high-frequency wave is superposed during the non-display time. Fig. 46 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown Fig. 45. In Figs. 45 and 46, the display time equals to the non-display time in length, similarly in Figs. 43 and 44. However, since the high-frequency wave is superposed during the non-display time, molecules of the liquid crystal used in the present embodiment (E>0) follow the electric field because of the high frequency of the superposed high-frequency wave, though the molecules themselves show the tendency to move, and hence the complete switching cannot be achieved. Accordingly, the optical change in the non-display time becomes sufficiently small compared with the change in the display time. That is, though the effective electric field for canceling the direct-current component is applied, the liquid-crystal molecules do not move following the electric field, so that the optical change is not substantially produced.

In this case, it is required that the pulse width of the high-frequency wave superposed on the liquid crystal is at least shorter than the time needed for the liquid crystal to optically change 50 % (preferably, shorter than the time needed for the liquid crystal to optically change 10 %).

With the liquid-crystal material used in the present embodiment, the pulse width of the high-frequency wave is required to be at least 50 μsec or less because the response time of the liquid crystal is 80 μsec. The pulse width of the high-frequency wave superposed in the embodiment is 3 μsec (frequency of 167 KHz, Vpp=+5V).

Drive Experiment (4)

The change of light transmittance intensity was examined in the same manner as described above by applying the pulse with the waveform of Fig. 47 to the sample-and-hold circuit.

The light transmittance intensity of the liquid crystal by using the gate signal with a different pulse width is plotted in Fig. 48. That is, Fig. 47 diagrammatically shows the electric field intensity applied to the liquid crystal when the switching signal and liquid-crystal-driving signal are applied to the circuit of Fig. 28 in accordance with the waveforms in which the non-display time becomes shorter than the non-display time, and Fig. 48 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 47. Fig. 48 shows the optical variation when the display time is different from the non-display time in length. The optical variation occurs in the range of 33% (1/3) to 66% (2/3) when the display time and the non-display time are as follows.

Display time : Non - display time = 10 msec : 5 msec

Drive Experiment (5)

The change of light transmittance intensity was examined in the same manner as described above by applying the pulse having the waveform of Fig. 49 to the sample-and-hold circuit.

The light transmittance intensity of the liquid crystal by using the gate signal with a different pulse width is plotted in Fig. 50. That is, Fig. 49 diagrammatically shows the waveforms of the switching signal and liquid-crystal-driving signal which are applied to the circuit of Fig. 28 for each tone (the drive method by which each scanning time is different from others) so as to display four tones without cancelling the electric field applied to the liquid crystal, and Fig. 10 shows the light transmittance change of the cell for each tone in response to the switching signal when the electric field is applied to the liquid-crystal cell in accordance with the waveforms shown in Fig. 49. In Fig. 49, the time needed for the first scanning is set 5 msec while the time needed for the second scanning is set 10 msec. In Fig. 50, it is not necessary to change the light intensity between the bright state and the dark state because the method of driving the liquid crystal does not have the non-display time for cancelling the electric field, so that the optical variation becomes 1% for the tone 0, 33 % for the tone 1, 67 % for the tone 2, and 100% for the tone 3. The four

different tones are obtained with two times of scanning for composing one frame.

Drive Method (6)

The change of light transmittance intensity was examined in the same manner as described above by applying the pulse having the waveform of Fig. 51 to the sample-and-hold-circuit.

The light transmittance intensity of the liquid crystal by using the switching signal with a different pulse width is plotted in Fig. 52. Fig. 51 shows the waveforms provided with the non-display time for canceling the applied electric field, wherein the display time prior to the non-display time is 4 msec, the display time after the non-display time is 8 msec, and the non-display time is 2 msec. The waveforms shown in the embodiment do not completely cancel the electric field applied to the liquid-crystal cell.

Fig. 52 shows the light transmittance intensity during the driving in accordance with the waveforms shown in Fig. 51. The transmittance for each tone in operation is 15% for the tone 0, 43% for the tone 1, 57% for the tone 2, and 86% for the tone 3. By the provision of the non-display time for cancelling the electric field applied to the liquid crystal, the loss in light intensity arises both in the bright state and the dark state, so that the optical dynamic range is reduced.

The four tones with the different intensities of the transmitted light (2^{3-1}) are obtained by three times of scanning (three fields) which compose one frame.

Drive Experiment (7)

Characteristics were examined with the constitution in which the light intensity of the light source is in synchronization with the signal for driving the liquid-crystal cell.

As the light source, a fluorescent lamp was used.

Fig. 53 shows the relation between the waveforms of the Fig. 53 shows the relation between the waveforms of the pulses applied to the sample-and-hold circuit and the variation in light intensity of the light source. The change of light transmittance intensity in this case was examined.

The light transmittance intensity of the liquid crystal by using the switching signal with a different pulse width is plotted in Fig. 54. That is, Fig. 53 diagrammatically shows the switching signal and liquid-crystal-driving signal which are applied to the circuit of Fig. 28 and the variation in intensity of the light source for the liquid crystal so as to display four tones by varying the light intensity for illuminating the liquid crystal in synchronization with the pulse applied to the liquid-crystal panel, and Fig. 54 shows the variation in light transmittance change of the cell for each tone in response to the switching signal when the electric field is applied to the liquid-crystal cell in accordance with the waveforms shown in Fig. 53.

This experiment is characterized in that the luminance of the backlight is varied in synchronization with the liquid-crystal-driving signal.

The frequency for operating the backlight in the display time prior to the non-display time was set 25 Hz. In the display time after the non-display time, the pulse for operating the backlight was not applied in the first 2 msec and the frequency of the pulse for operating the back-light which was applied after the first 2 msec was set 50 Hz. In the non-display time, the pulse for operating the backlight was not applied.

In Fig. 54, the same switching of the liquid crystal as in Fig. 52 is shown, but the difference in intensity of the transmitted light between each adjacent tones is sufficiently large because the frequency of the pulse for operating the light source is varied and so the brightness of the screen is changed. In this case, the optical variation becomes 50% for the tone 0, 35% for the tone 1, 65% for the tone 2, and 90% for the tone 3 (the intensity 100% of the transmitted light is based on the brightness when the frequency for driving the backlight is 25 MHz.

EXAMPLE 2

Fabrication of TFT Matrix Cell

Figs. 55 and 56 are cross sectional views of a ferroelectric liquid-crystal cell using an amorphous-silicon TFT, and Fig. 57 is a perspective view of the substrate of TFT. Each of the drawings mentioned above shows the panel constitution in accordance with the present invention.

The liquid-crystal cell is fabricated in accordance with the following steps.

1. A film of Ta was deposited by sputtering on a glass or plastic substrate 31, and then formed into a specified pattern so as to form gate wiring 32 and a gate electrode 35.
2. On the substrate obtained in the step 1, an insulating film 33 (SiNx), a semiconductor layer 40 (a-Si), an n+ diffused layer 41 (a-Si doped with phosphorous) and an n+ diffused layer 41 (a-Si doped with phosphorous) were successively formed by plasma CVD. The said semiconductor layer 40 (a-Si) and the n+ diffused layer 41 (a-Si doped with phosphorus) were subjected to patterning.
3. An ITO film was deposited by sputtering on the substrate obtained in the step 2, which was then subjected to patterning so as to form a pixel electrode 37.
4. A Ti film was deposited by sputtering on the substrate obtained in the step 3, which was then subjected to patterning so as to form a source electrode 36 and a drain electrode 38.
5. On the substrate obtained in the step 4, an in-

sulating film 42 (SiO_2) was formed to the thickness of 500 Å.

6. On the substrate obtained in the step 5, a light-shading layer 44 was formed.

7. A counter electrode 45 composed of an ITO film was formed by sputtering on the other substrate.

8. On the substrate obtained in 7, an insulating layer 42 (SiO_2) was formed to the thickness of 500 Å. The thickness of the insulating layer can be set in the range of 300 to 5000 Å, preferably in the range of 500 to 2000 Å.

9. On the substrates obtained in the steps 6 and 8, an orientation layer 43 (PSI-X-A-2001 available from Chisso Corporation or RN715 available from Nissan Chemical Industries, Ltd.) was formed to the thickness of 400 Å with a spin coater (46 and 47). The thickness of the orientation film can be set in the range of 100 to 5000 Å, preferably in the range of 500 to 2000 Å.

10. The substrates 46 and 47 fabricated in the step 9 were subjected to uni-axial orientation treatment which was performed by rubbing techniques with the use of rayon-type cloth. In this case, rubbing was performed so that the substrates 46 and 47 would have the same rubbing direction when they were joined together.

11. Between the upper and lower substrates which had gone through the steps 1 to 10, silica beads with the diameter of 3.0 µm were dispersed so as to serve as spacers 6, and the substrates were joined together with a sealing member of epoxy resin.

12. The ferroelectric liquid-crystal composition in accordance with the present invention was injected by vacuum injection techniques to the panel fabricated through the foregoing steps. After injection, the opening for injection was hermetically sealed with a UV-setting resin of acrylic type.

Drive Experiment (1)

The change of light transmittance intensity was similarly examined by applying the pulses having the waveforms of Fig. 58 to each terminal of the gate, source, common electrodes. That is, Fig. 58 shows the waveforms of the signals applied to each of the gate, source, and common terminals of the TFT panel and of the electric field applied to the liquid crystal when high-frequency waves are superposed during the non-display time.

The light transmittance intensity of the liquid crystal using the gate signal with a different pulse width is by using the gate signal with a different pulse width is plotted in Fig. 59. That is, Fig. 59 shows the variation in light transmittance in response to the switching signal when the electric field is applied to the liquid-crystal cell in accordance with the waveforms shown in Fig. 58.

This experiment is characterized in that a high-frequency wave is applied from the common terminal to the liquid crystal during the non-display time.

The high-frequency wave superposed on the liquid crystal during the non-display time had the frequency of 250 KHz. In this case, V_{pp} was +5V and each of the display time and the non-display time was 4 msec.

Fig. 59 shows that the switching, in response to the gate signal with the shorter width than the optical response of the liquid-crystal material was performed, though the driving in response to the gate signal with the width of 1 µsec or less, which was performed above with an equivalent circuit (see Fig. 46), was not performed, and that the optical difference in intensity of the transmitted light can be obtained in practice with the TFT panel by the method in which high-frequency waves are superposed.

In this case, the change of light transmittance intensity in the OFF and ON states were approximately 22% and 79%, respectively.

Drive Experiment (2)

The change of light transmittance intensity was similarly examined by applying the pulses with the waveforms of Fig. 60 to each terminal of the gate, source, common electrodes of the cell.

The light transmittance intensity of the liquid crystal by using the gate signal with a different pulse width is plotted in Fig 61. That is, Fig. 60 shows the waveforms of signals applied to each of the gate, source, and common terminals of the TFT panel with the address at which the non-display time is shorter than the display time and of the electric field applied the liquid crystal, and Fig. 61 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 60.

This experiment is characterized in that the display time and the non-display time are different in length. The display time and the non-display time used in the embodiment were 9 msec and 3 msec, respectively.

Fig. 61 shows that the switching in response to the gate signal with the shorter width than the optical response of the liquid-crystal material was performed, though the driving in response to the gate signal with the width of 1 µsec or less, which was performed above with an equivalent circuit (see Fig. 46), was not performed, and that the optical difference in intensity of the transmitted light can be obtained in practice with the TFT panel due to the difference in length of the display time and the non-display time.

In this case, the change of light transmittance intensity in the OFF and ON states were approximately 25% and 75%, respectively.

Drive Experiment (3)

The change of light transmittance intensity was similarly examined by applying the pulses with the waveforms of Fig. 62 to each terminal of the gate, source, common electrodes of the cell. The light transmittance intensity of the liquid crystal by using the gate signal with a different pulse width is plotted in Fig. 63. That is, Fig. 62 diagrammatically shows the waveforms of the switching signals and the liquid-crystal-driving signals to the gate, source, and common electrodes of the TFT panel for each tone (the drive method in which each scanning time is different in length) so as to display four tones without canceling the electric field applied to the liquid crystal, and Fig. 63 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 62.

This experiment is characterized by the waveform of the electric field applied to the electrode which is not at all cancelled. The former display time and the latter display time used in this case are 4 msec and 8 msec, respectively.

Fig. 63 is characterized in that the switching in response to the gate signal with the shorter width than the optical response of the liquid-crystal material was performed, though the driving in response to the gate signal with the width of 1 μsec or less, which was performed above with an equivalent circuit (see Fig. 46), was not performed, and that the four tones were obtained. The optical variation were 0% for the tone 0, 33% for the tone 1, 67% for the tone 2, and 100% for the tone 3. With the two times of field scanning composing one frame, the four tones with different intensities of the transmitted light were obtained.

However, this drive method is not preferable under such circumstances as the same image is displayed for a long time, because the direct-current component is applied to a specific portion.

Drive Experiment (4)

The change of light transmittance intensity was similarly examined by applying the pulses having the waveforms of Fig. 64 to each terminal of the gate, source, common electrodes of the cell. That is, Fig. 65 diagrammatically shows the waveforms of the switching signals and the liquid-crystal-driving signals to the gate, source, and common electrodes of the TFT panel for each tone (the drive method in which each field scanning time is different in length) so as to display the four tones in a combination of waveforms by which the electric field applied to the liquid crystal is cancelled.

The light transmittance intensity of the liquid crystal by using the gate signal with a different pulse width is plotted in Fig. 65. That is, Fig. 65 shows the light transmittance change of the liquid-crystal cell in response to the switching signal when the electric field is applied to the cell in accordance with the waveforms shown in Fig. 65.

This experiment is characterized by the provision of the non-display time during which the pulse for cancelling the electric field applied to the liquid crystal is applied. The former display time, the latter display time, and the non-display time are 4 msec, 8 msec, and 2 msec in length, respectively. As shown in Fig. 65, this experiment is characterized in that the switching in response to the gate signal with the shorter with than the optical response of the liquid-crystal material was performed, though the driving in response to the gate signal with the width of 1 μsec or less, which was performed above with an equivalent circuit (see Fig. 46), was not performed, and that the four tones were obtained. The optical variation were 14% for the tone 0, 43% for the tone 1, 57% for the tone 2, and 86% for the tone 3. With the three times of scanning composing one frame, the four tones with different intensities of transmitted light (2^{3-1} tones) were obtained.

However, if the waveform shown in Fig. 64 is applied in the pulse setting of the present embodiment, the electric field was not completely canceled.

According to the results of the experiments in the embodiments 1 and 2 shown above, the following conclusions were primarily obtained:

(a) By turning the switching device OFF in the state in which the electric field is applied to the liquid crystal, the all switching devices make one screen with the gate signal with the width shorter than the time needed for the liquid-crystal molecules to optically switch.

(b) In order to reduce the variation in luminance of display resulting from the variation in brightness during the non-display time within the period of displaying one frame, it is effective to: make the non-display time shorter than the display time; superpose a high-frequency wave on the liquid-crystal cell during the non-display time; and vary the intensity of light from the light source in synchronization with the scanning of the panel.

(c) By differentiating the intensity of light transmitted by the liquid crystal for each of m times of field scanning for displaying one frame, it becomes possible to display the maximum number 2^m of tones that can be ob- tained from the scanning for displaying one frame.

By using the liquid crystal with spontaneous polarization, charging the liquid crystal through the charging of the switching device during the period of time shorter than the response time of the liquid crystal, and driving the liquid crystal molecules with the applied electric field, the scanning rate is increased, with a result that one frame can be composed of a

plurality of fields and hence display images in a plurality of tones can be obtained in accordance with a combination of the fields.

Claims

1. A method of driving an active-matrix liquid-crystal display device including switching elements connected to scan lines and data lines, and pixel electrodes for applying an electric field to a liquid crystal with the aid of the switching elements, the switching elements and the pixel electrodes being arrayed in a matrix, and the liquid crystal being composed of a liquid crystal with spontaneous polarization, comprising the steps of:

   applying the electric field to the liquid crystal through the switching elements and the pixel electrodes for a time shorter than an electro-optical response time of the liquid crystal, thereby charging the liquid crystal to excite molecules thereof;

   scanning the liquid crystal lying at the pixel electrodes corresponding to all the scan lines, by applying the electrical field in linear sequential mode, thereby forming one imaging field;

   forming one frame by combining a plurality of the imaging fields serially; and

   providing as a result a plurality of tones with a displayed image.

2. A method of driving an active-matrix liquid crystal display device according to claim 1, wherein the imaging fields forming one frame each are scanned during the same time period.

3. A method of driving an active-matrix liquid-crystal display device according to claim 1, wherein the imaging fields forming one frame are scanned during different time periods.

4. A method of driving an active-matrix liquid-crystal display device according to claim 1, wherein the frame comprises n units of imaging fields to provide 2^n tones.

5. A method of driving an active-matrix liquid-crystal display device according to claim 1, wherein the electrical field has such magnitude and polarity as to be cancelled during a time period for forming one frame.

6. A method of driving an active-matrix liquid-crystal display device according to claim 1, wherein the electrical field has such magnitude and polarity as to be cancelled during a time period for forming a plurality of frames.

7. A method of driving an active-matrix liquid crystal display device according to claim 1 further comprising the step of applying a high frequency voltage having a cycle time shorter than the electro-optical response time of the liquid crystal to the liquid crystal for cancelling the applied electrical field.

FIG. 1

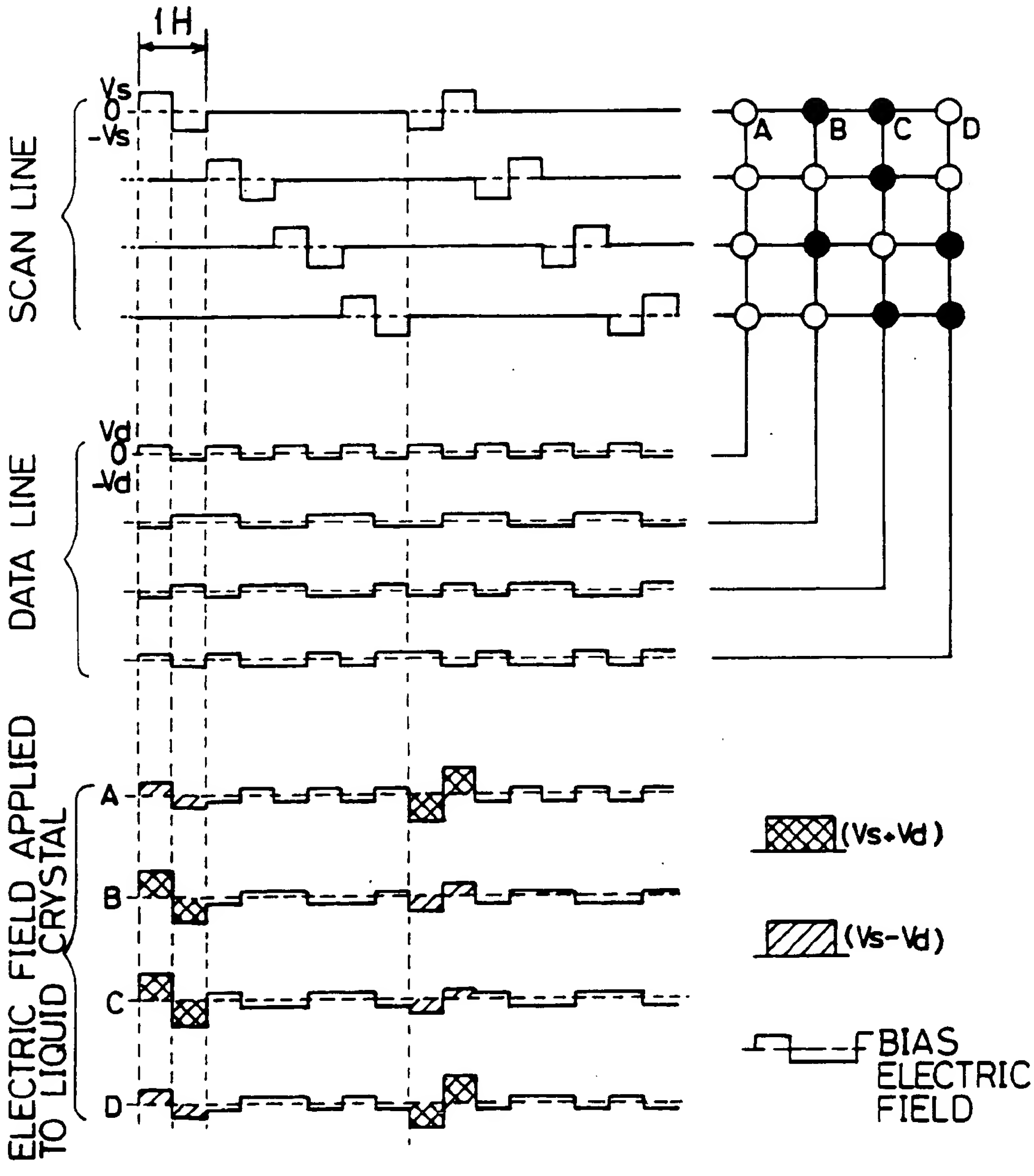

1H
Vs
0
-Vs
SCAN LINE
A
B
C
D
Vd
0
-Vd
DATA LINE
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
A
B
C
D
(Vs+Vd)
(Vs-Vd)
BIAS ELECTRIC FIELD

FIG. 2

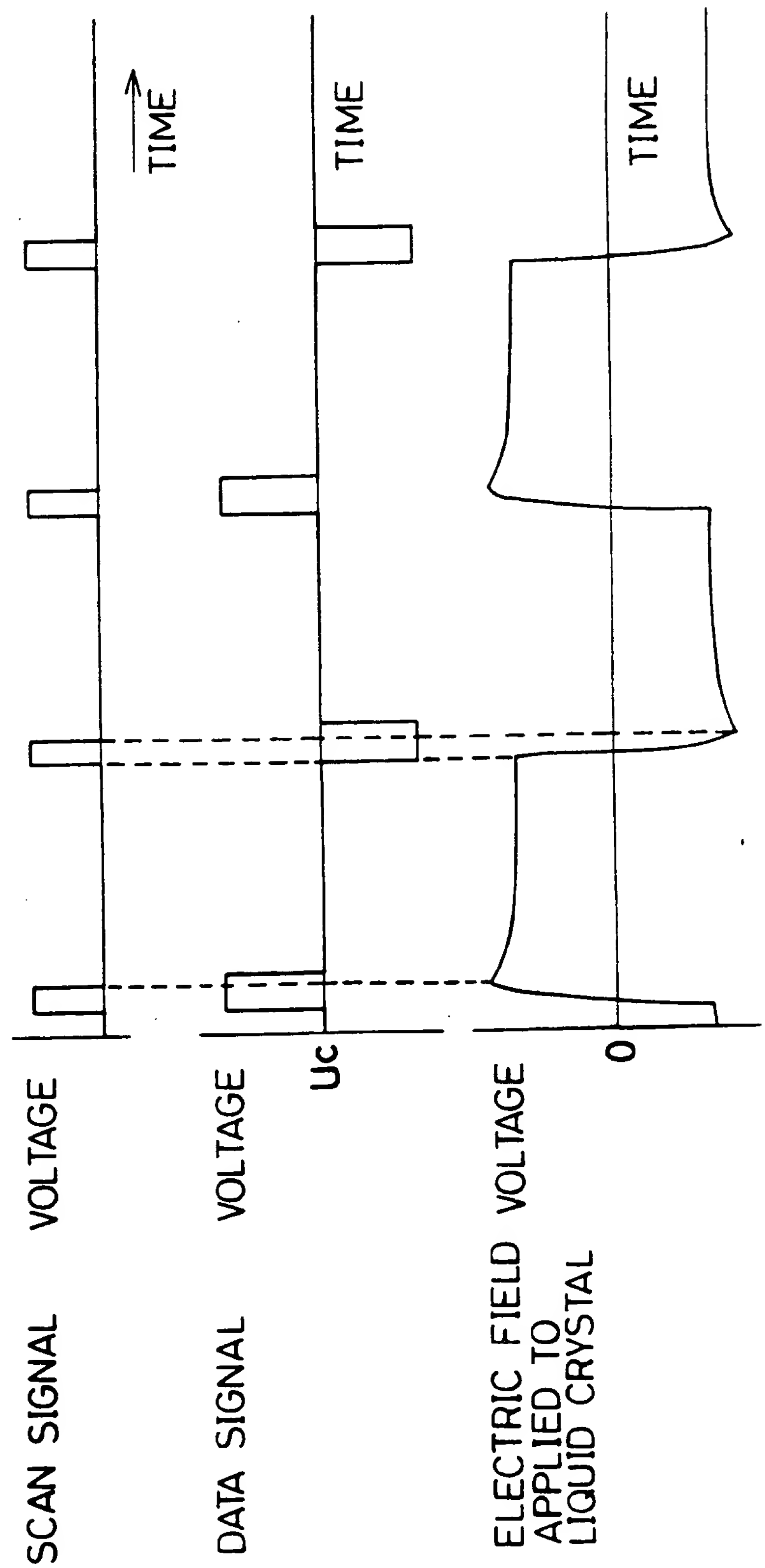

SCAN SIGNAL VOLTAGE
TIME
DATA SIGNAL VOLTAGE
Uc
TIME
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL VOLTAGE
0
TIME

FIG. 3

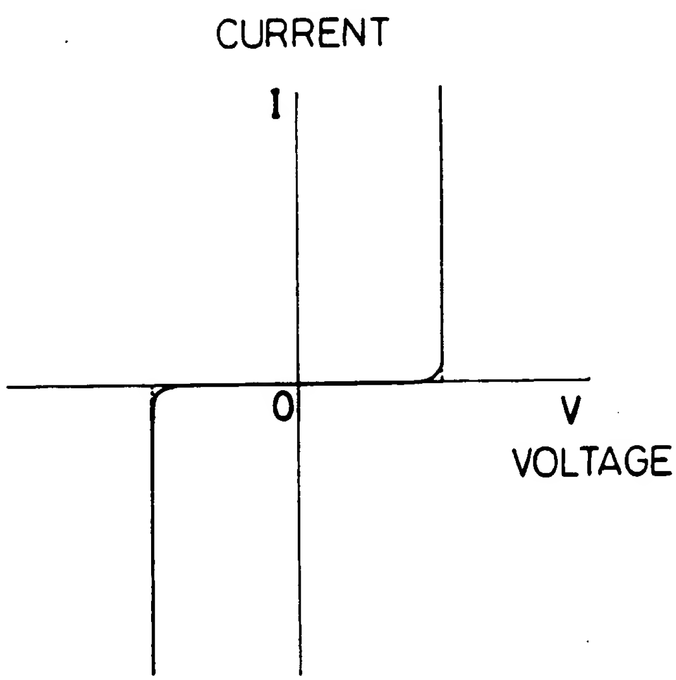


FIG. 4

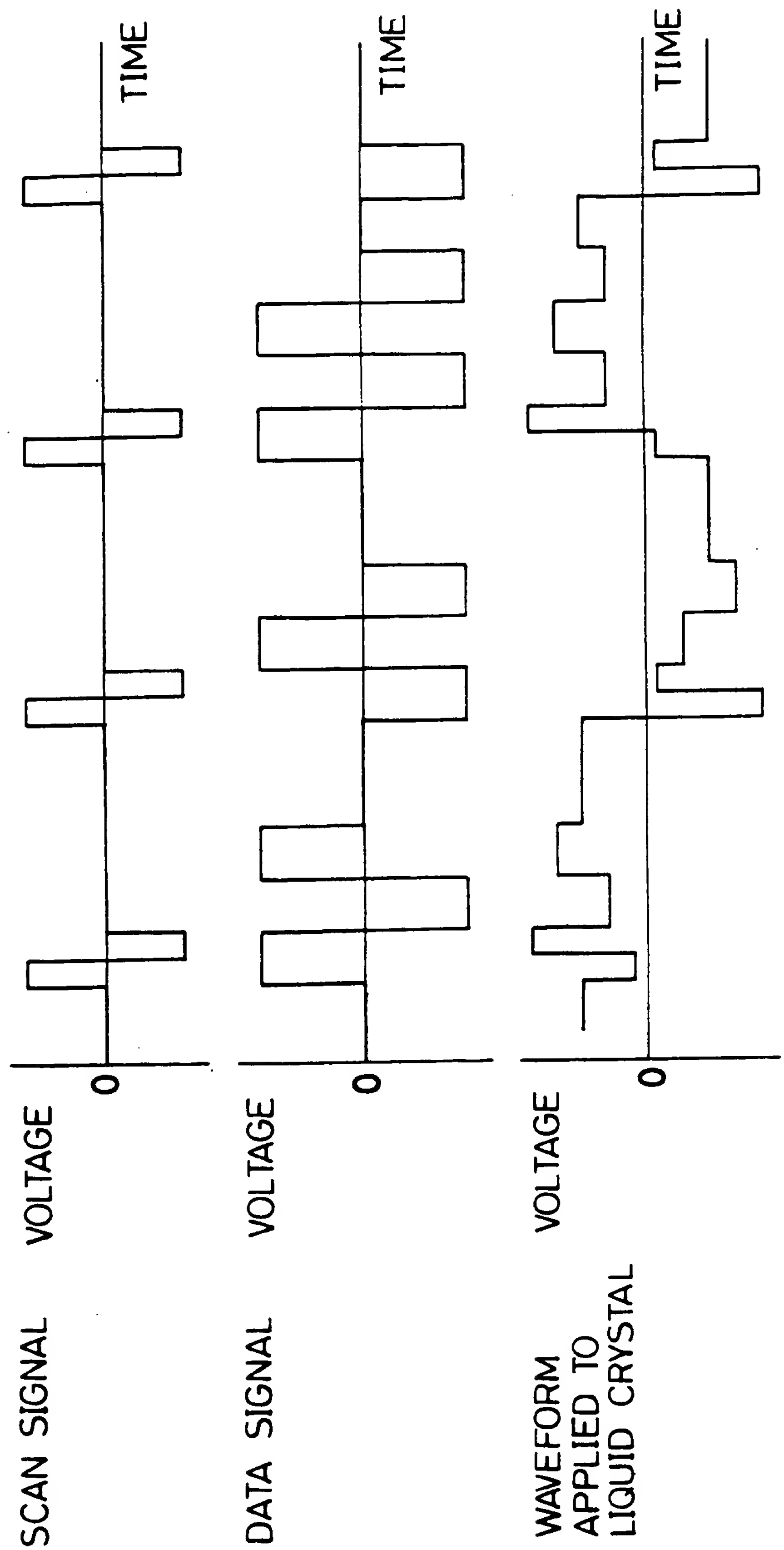

SCAN SIGNAL
VOLTAGE
0
TIME
DATA SIGNAL
VOLTAGE
0
TIME
WAVEFORM APPLIED TO LIQUID CRYSTAL
VOLTAGE
0
TIME

FIG. 5

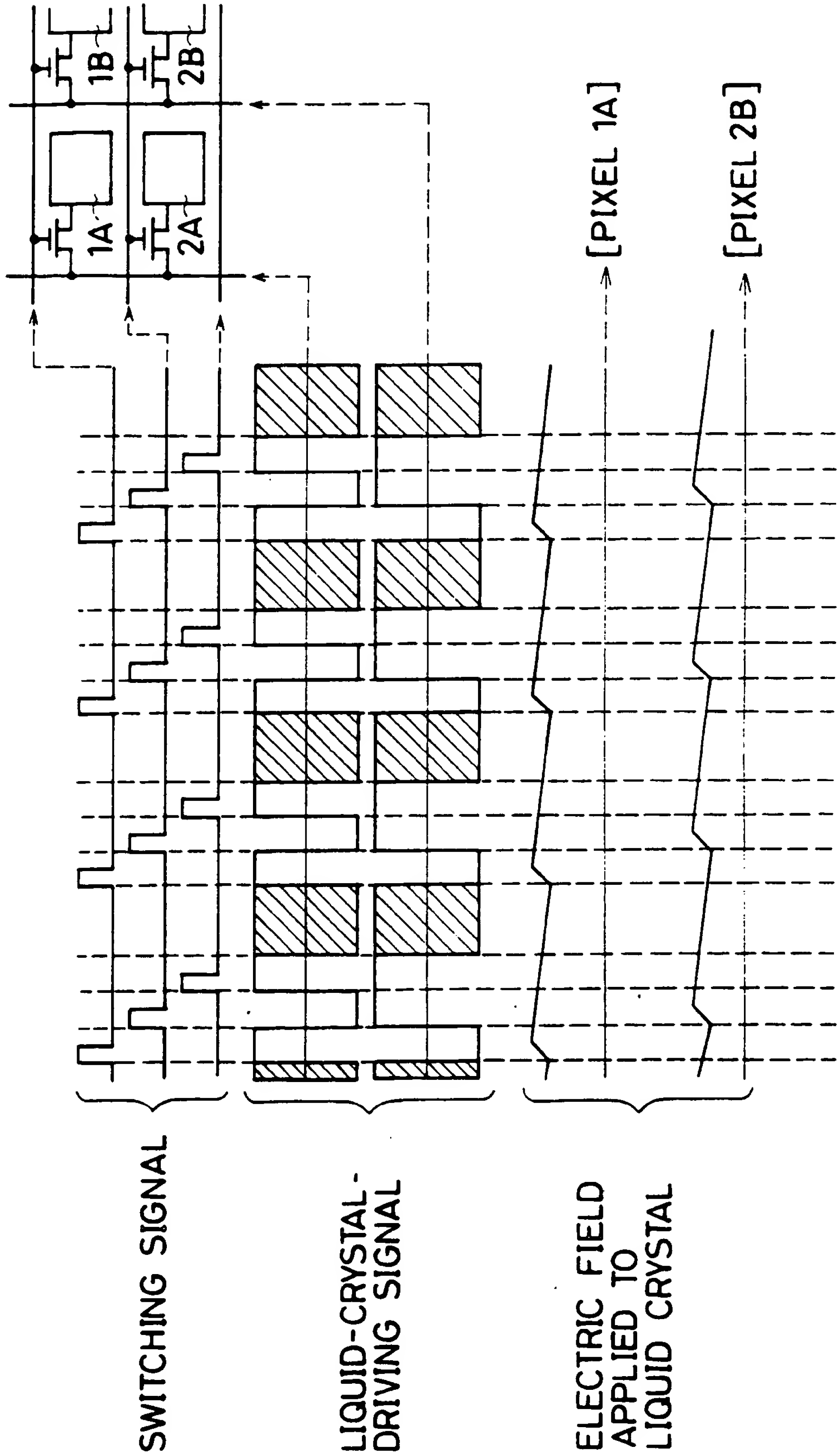

1A
1B
2A
2B
[PIXEL 1A]
[PIXEL 2B]
SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL

FIG. 6

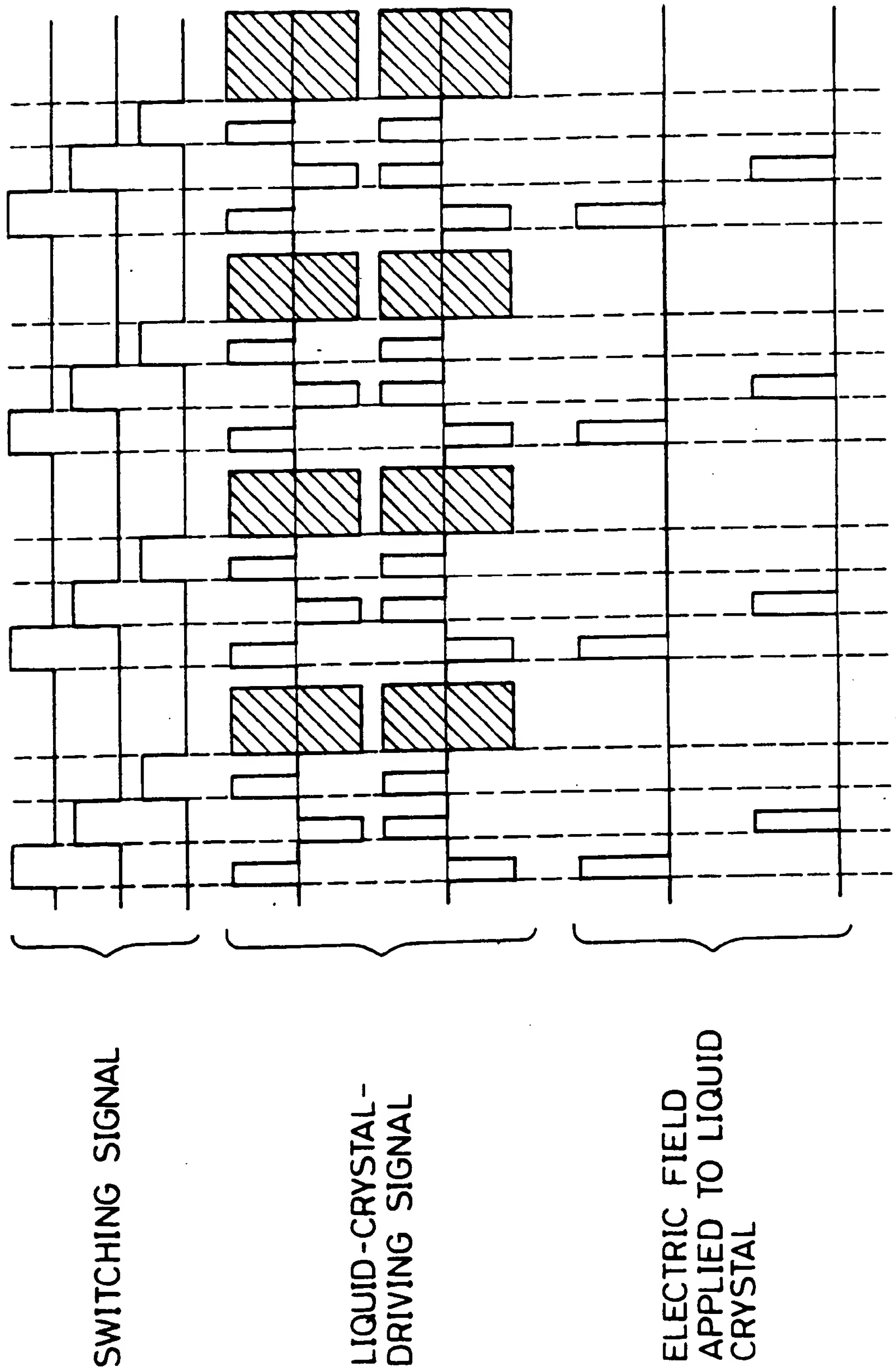
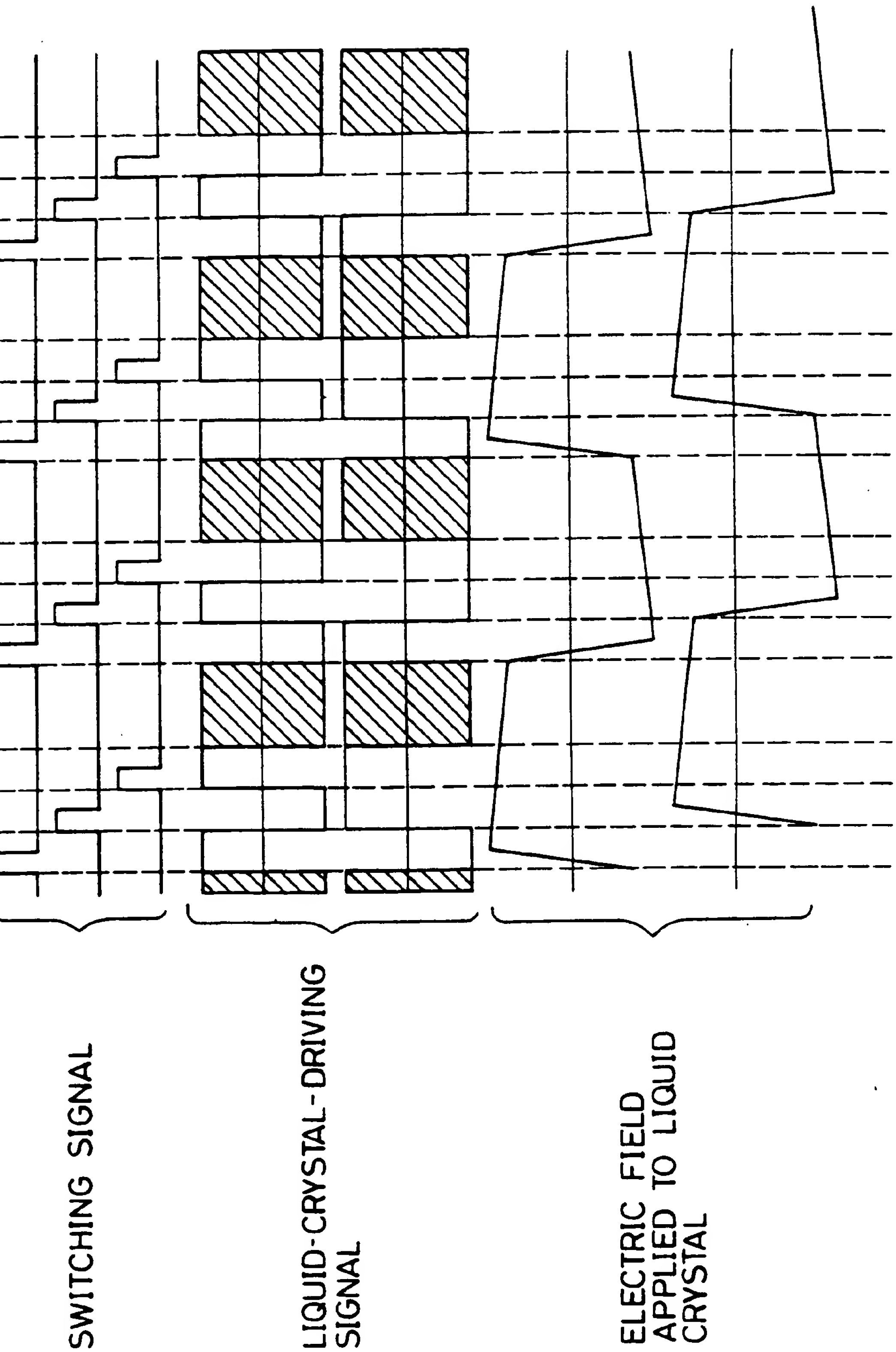

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL

FIG. 7


SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL

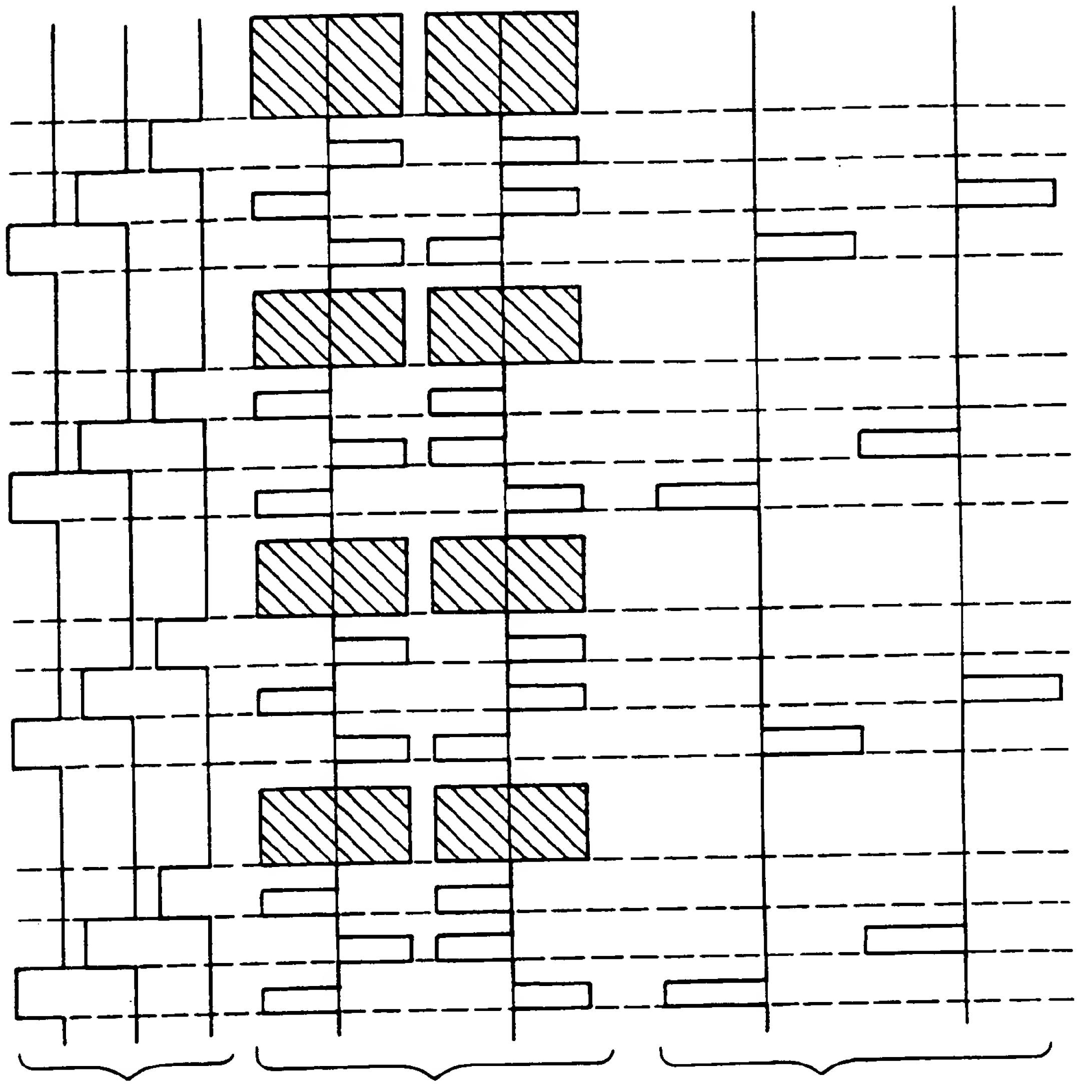

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL

FIG. 8

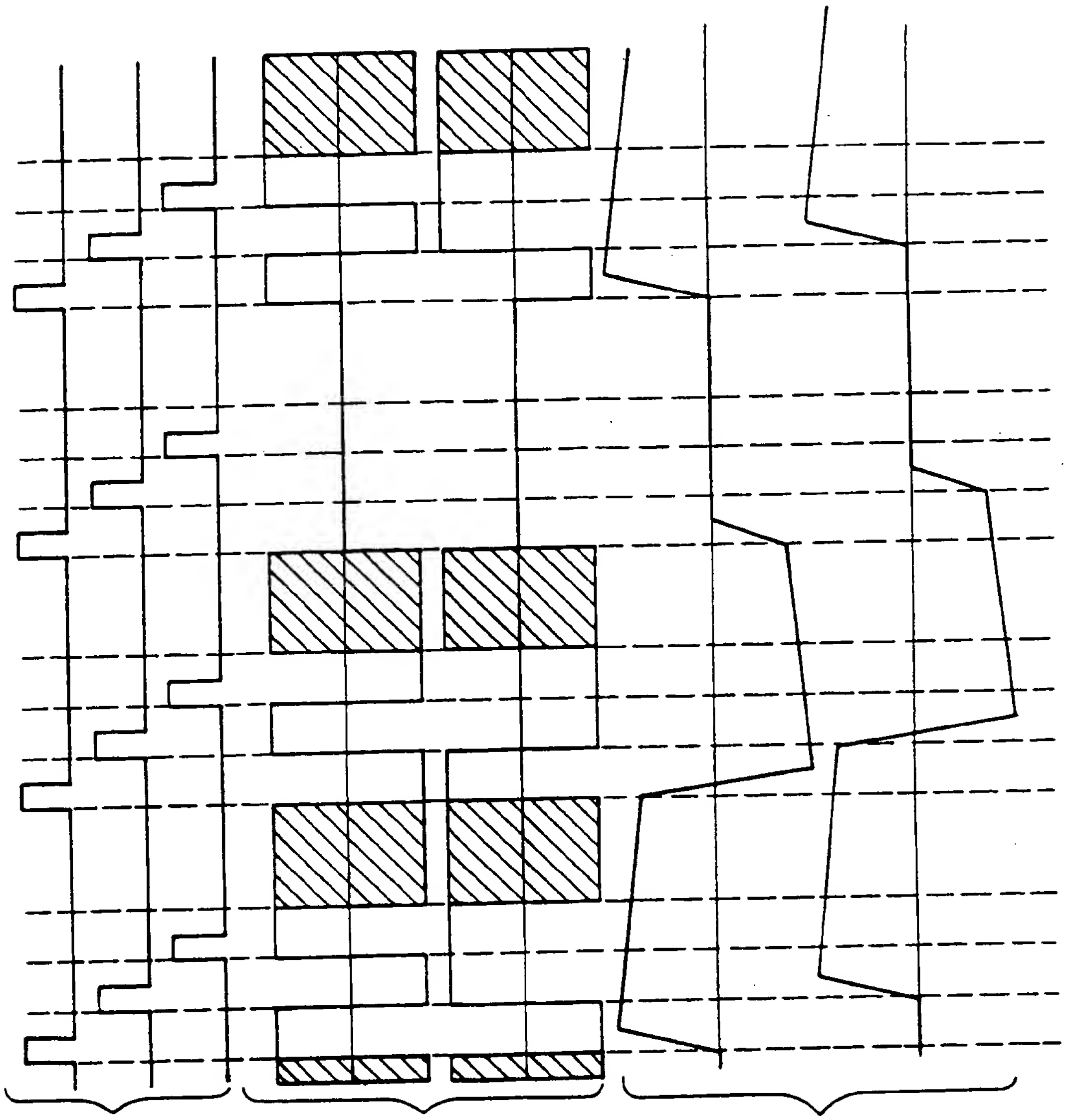

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL

FIG. 9

FIG. 10

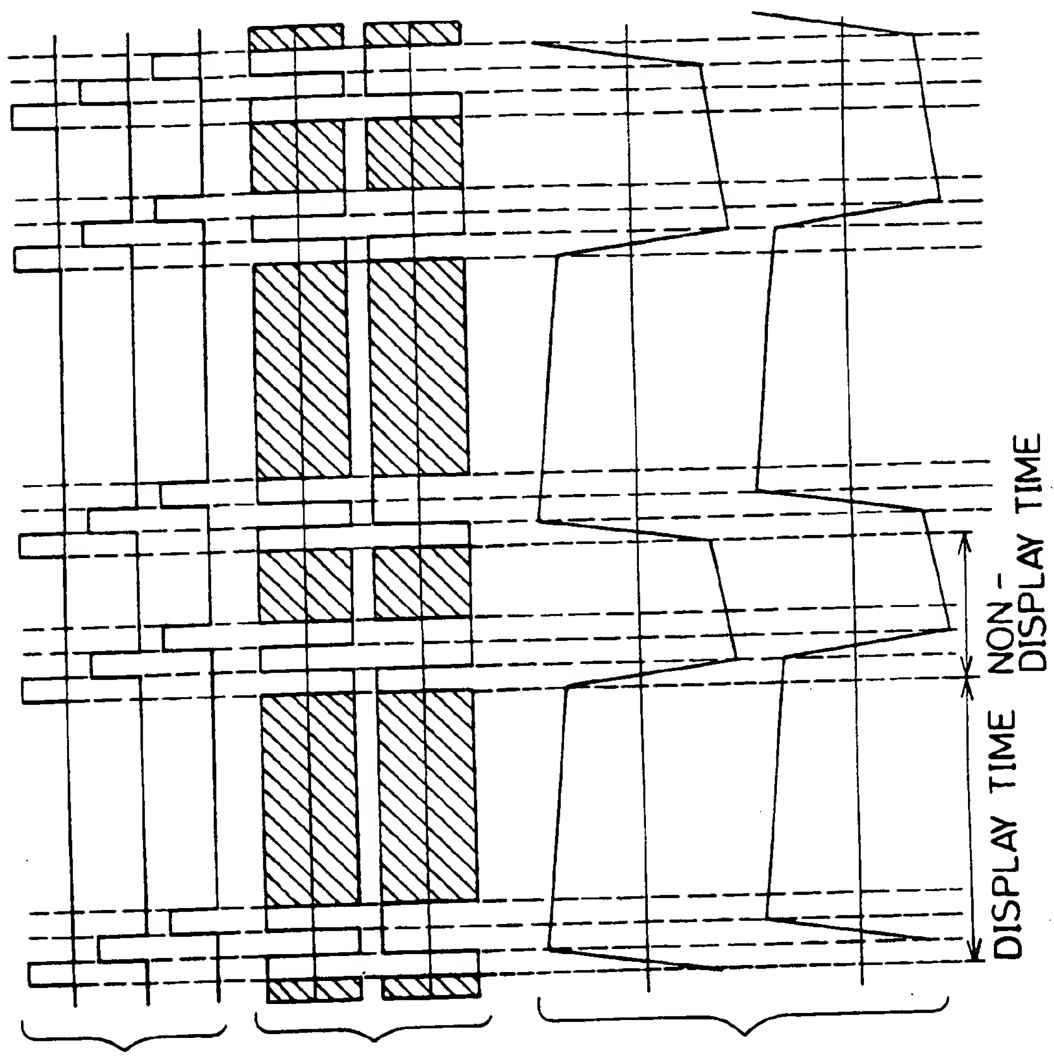

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
DISPLAY TIME
NON-DISPLAY TIME

FIG. 11

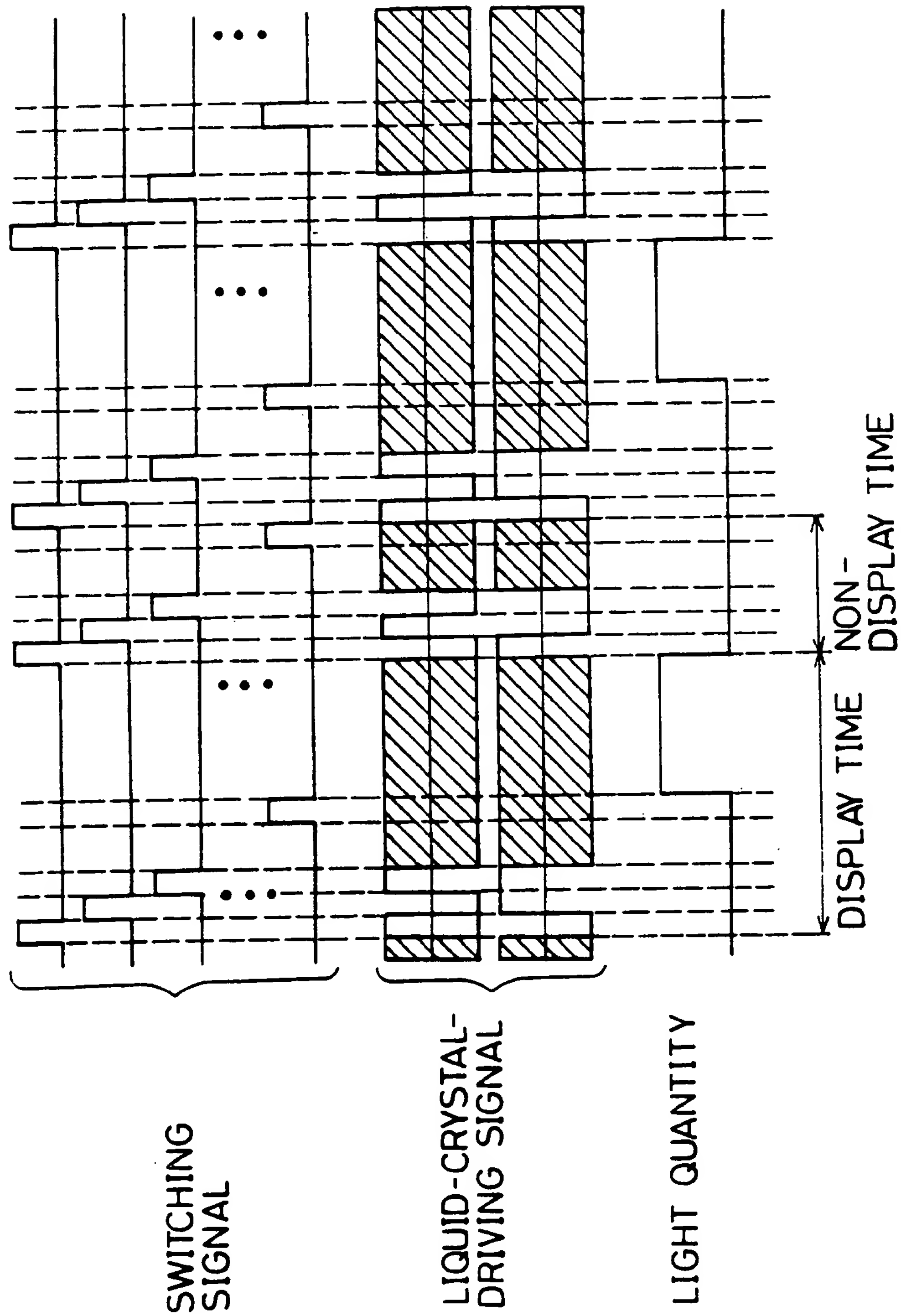

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
LIGHT QUANTITY
DISPLAY TIME
NON-DISPLAY TIME

FIG. 12

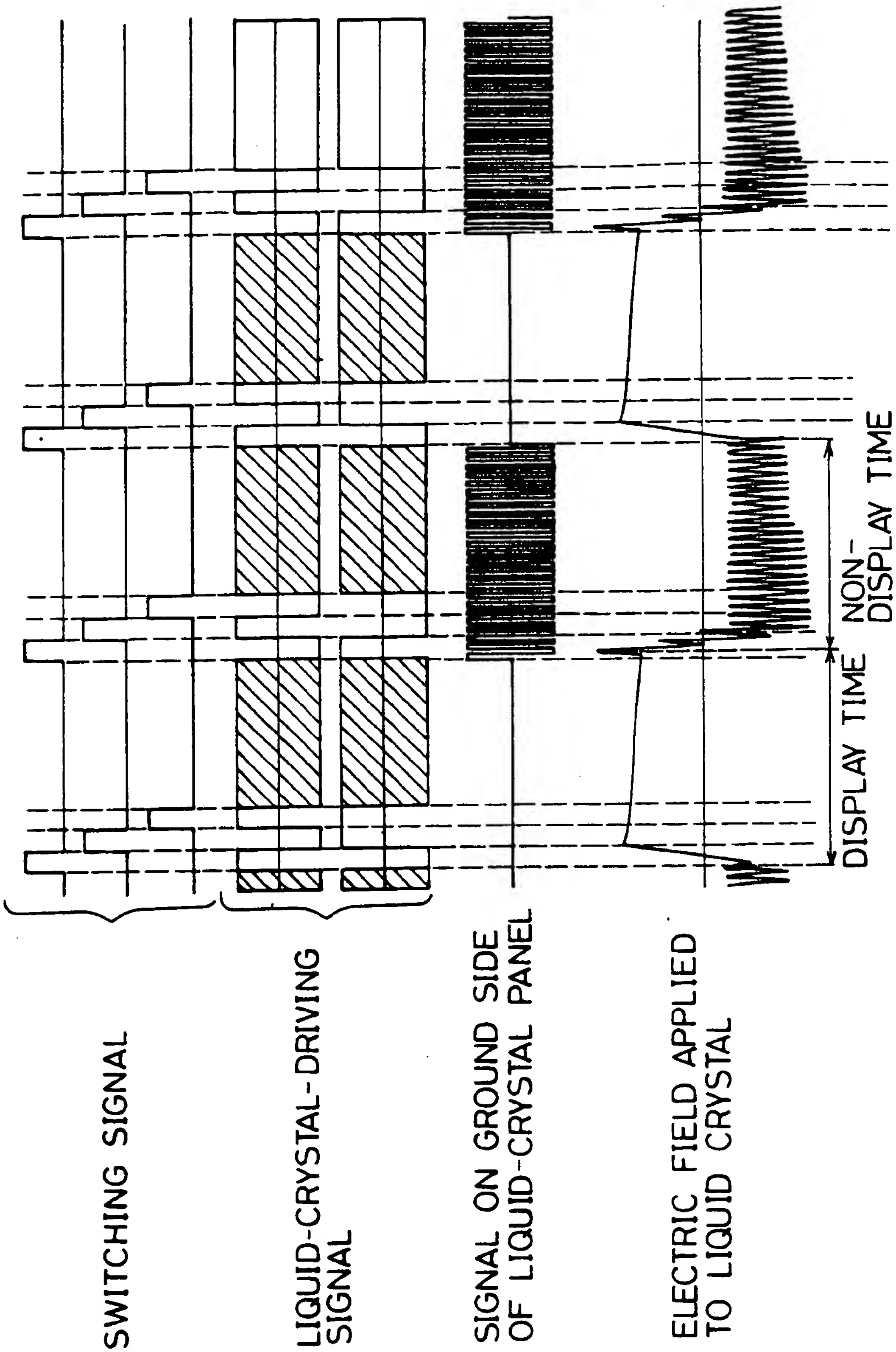

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
SIGNAL ON GROUND SIDE OF LIQUID-CRYSTAL PANEL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
DISPLAY TIME
NON-DISPLAY TIME

FIG. 13

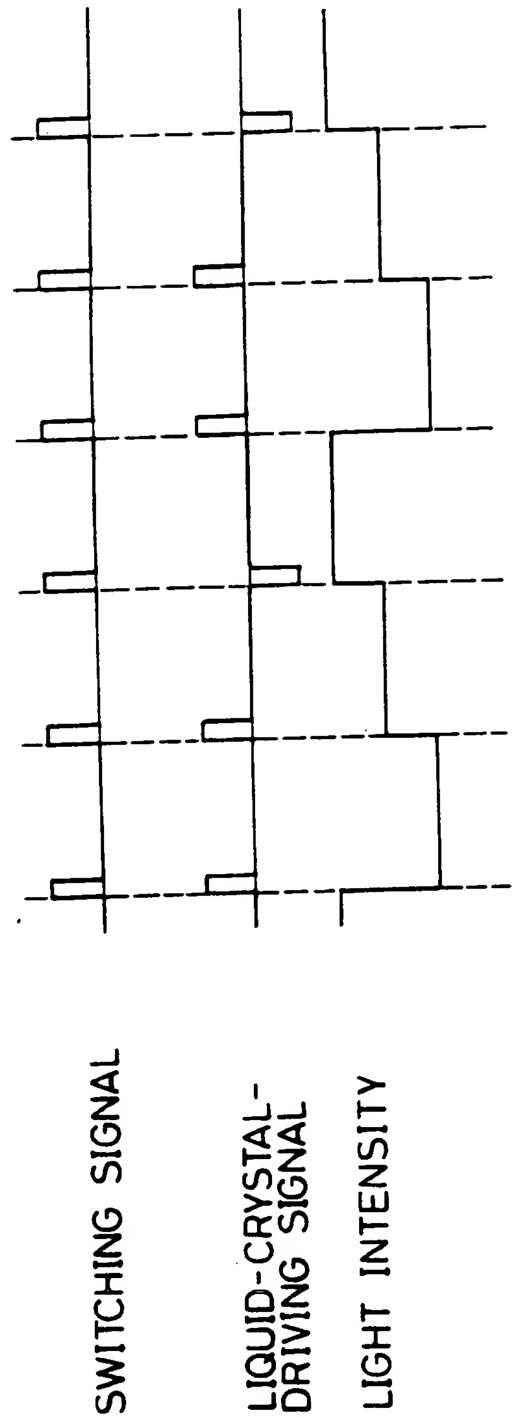

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
LIGHT INTENSITY

FIG. 14

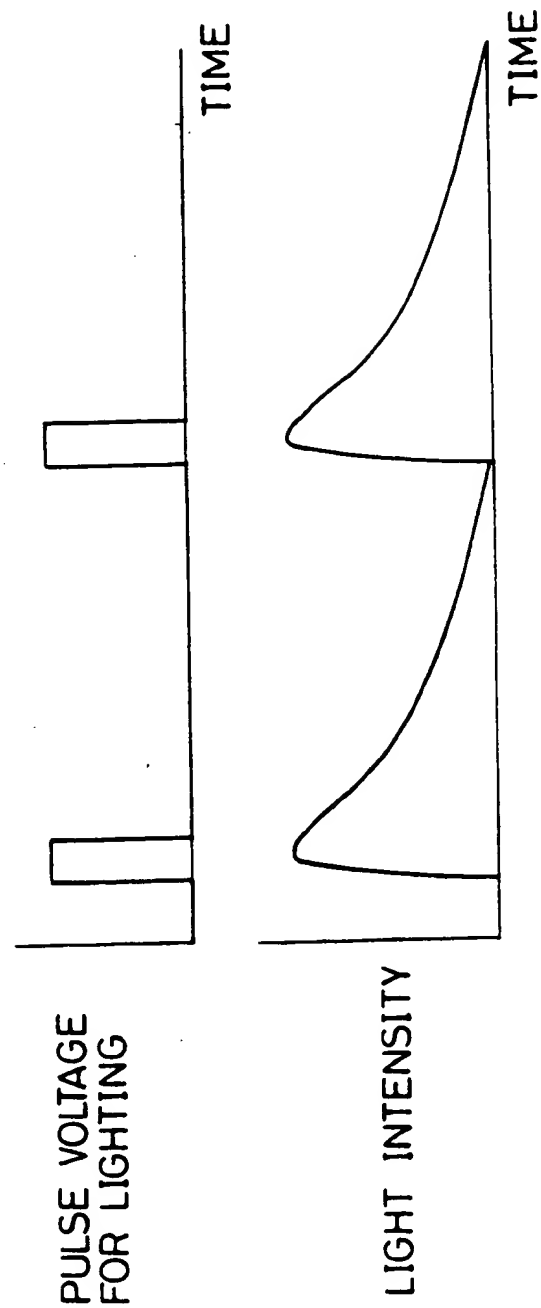


FIG. 15

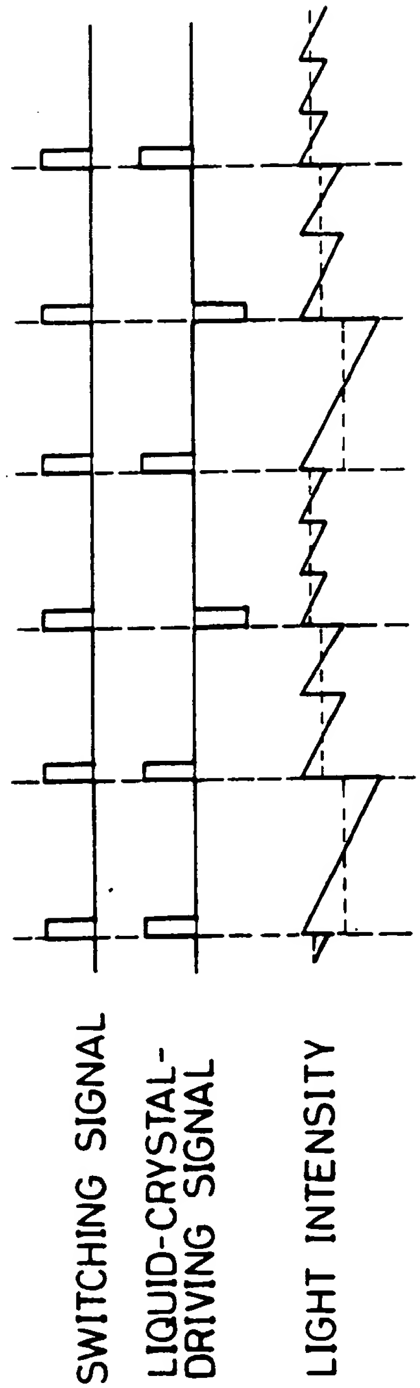

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
LIGHT INTENSITY

FIG. 16

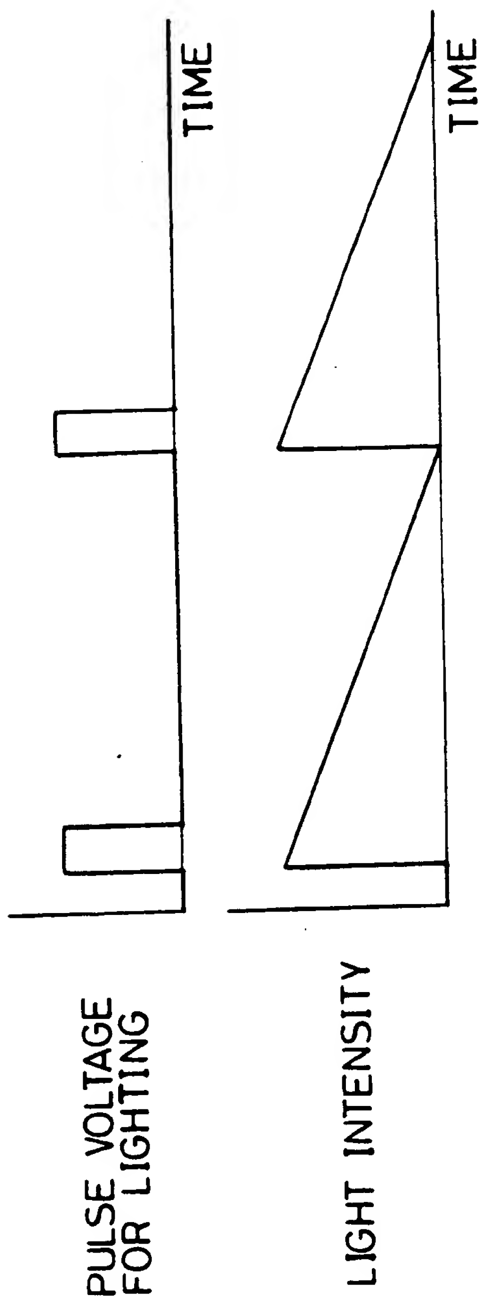


FIG. 17

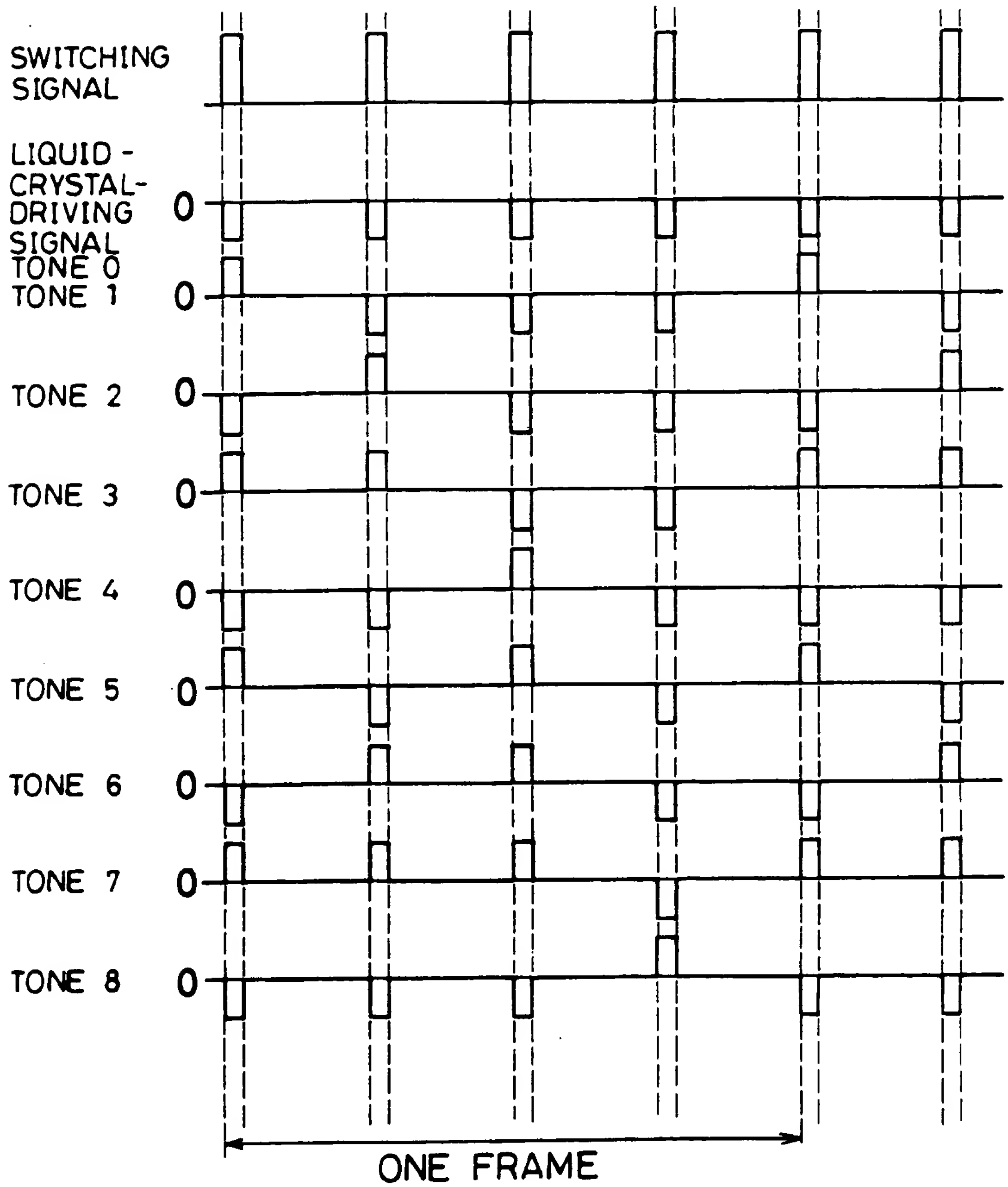

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0
TONE 1
TONE 2
TONE 3
TONE 4
TONE 5
TONE 6
TONE 7
TONE 8
0
ONE FRAME

FIG. 18

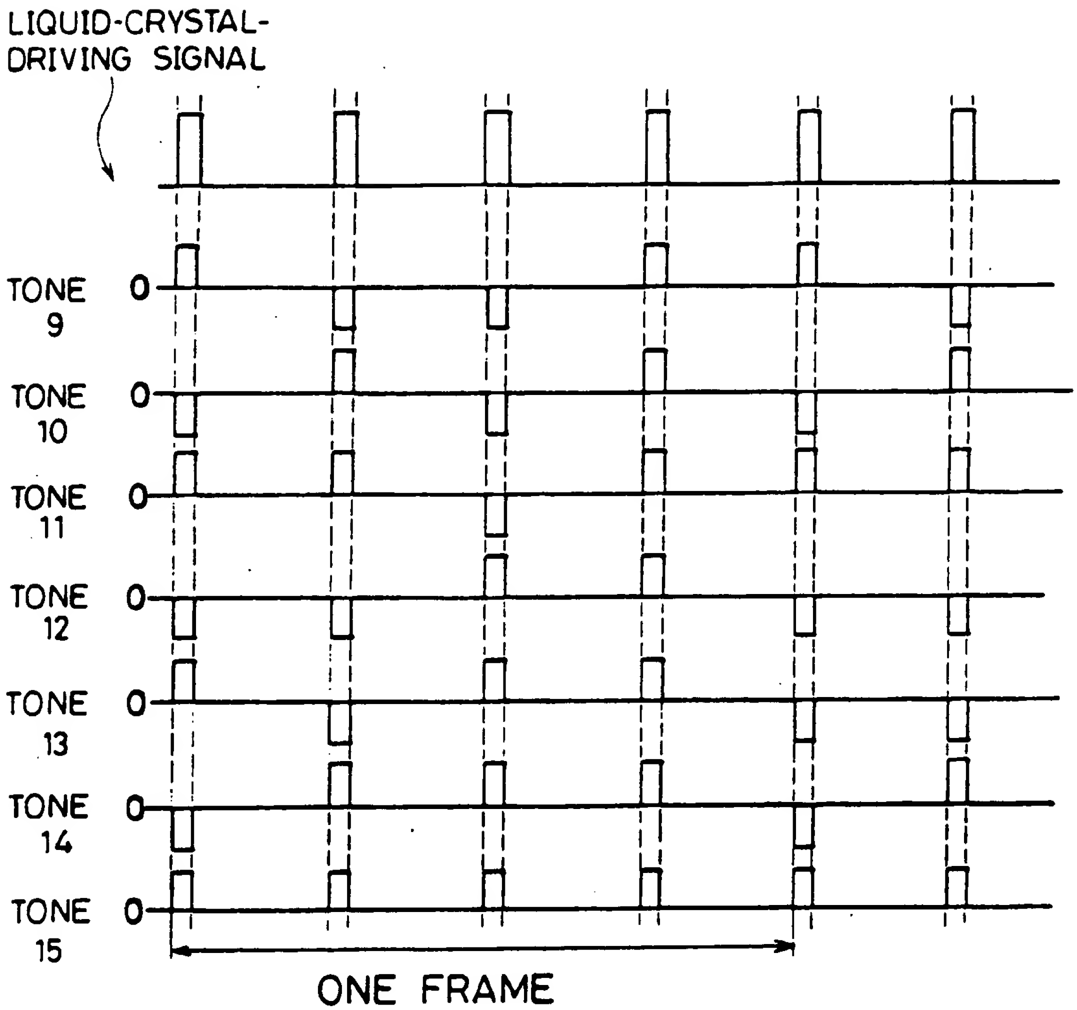

LIQUID-CRYSTAL-
DRIVING SIGNAL
TONE 9
0
TONE 10
0
TONE 11
0
TONE 12
0
TONE 13
0
TONE 14
0
TONE 15
0
ONE FRAME

FIG. 19

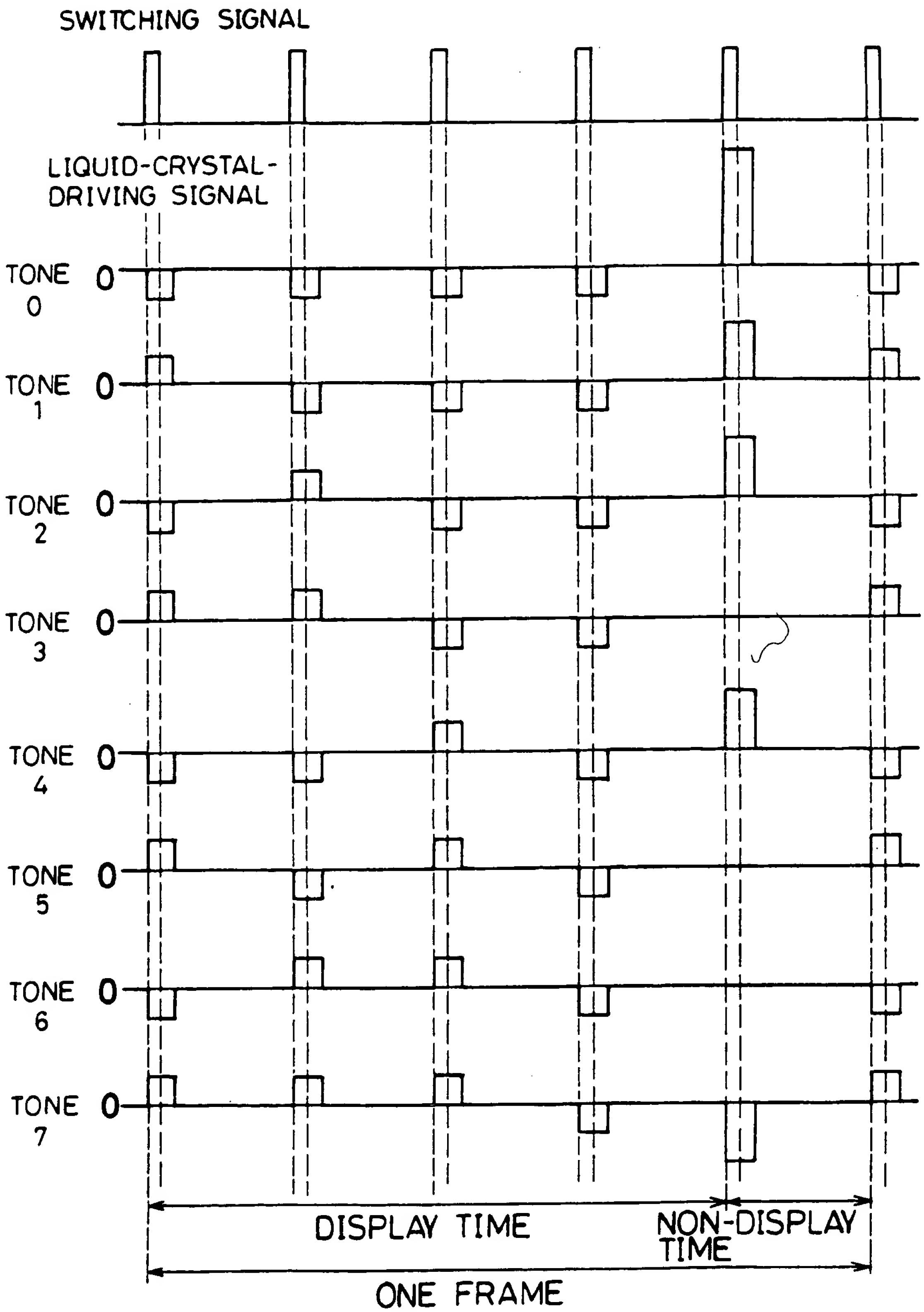

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0
TONE 1
TONE 2
TONE 3
TONE 4
TONE 5
TONE 6
TONE 7
0
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 20

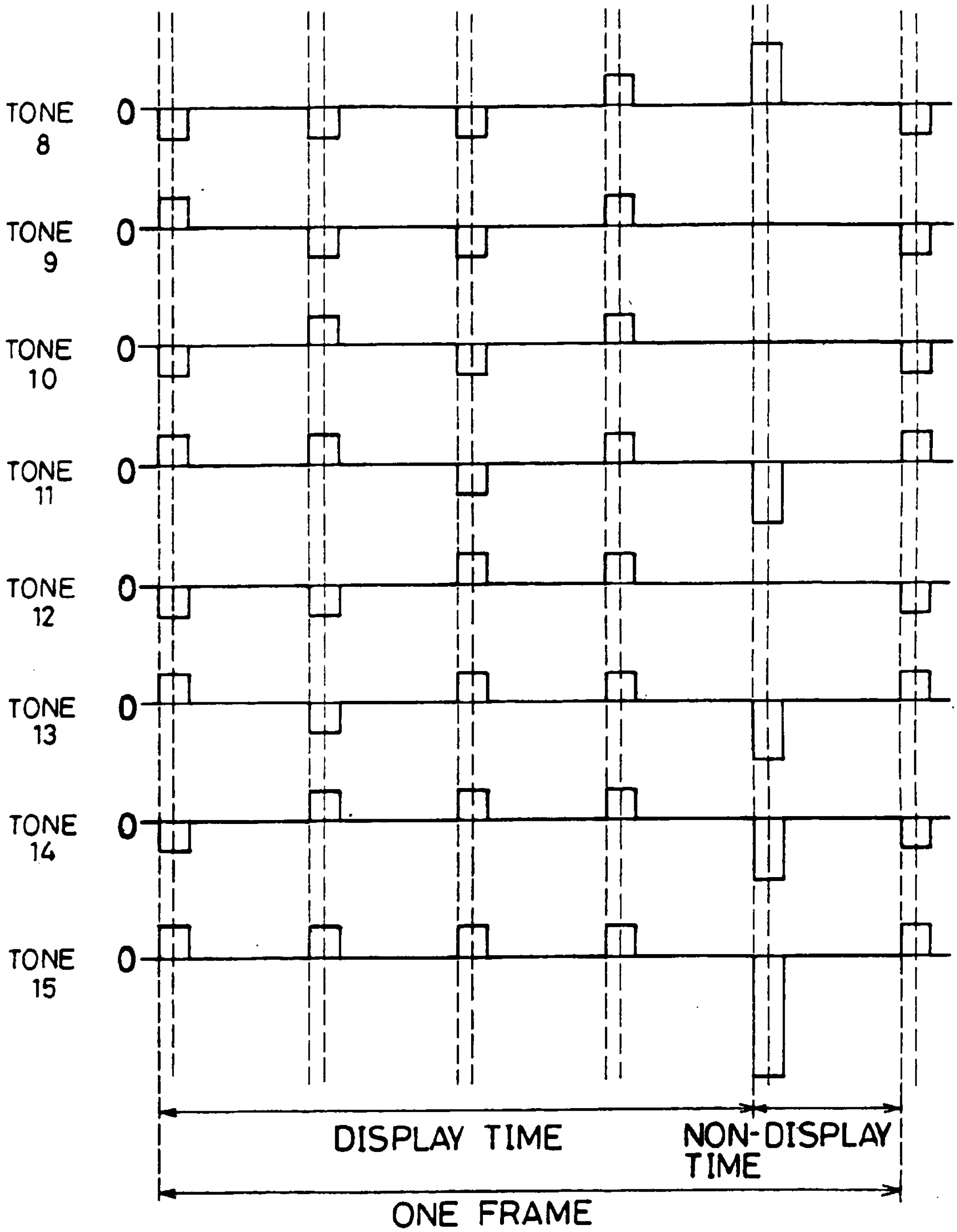

TONE 8
0
TONE 9
0
TONE 10
0
TONE 11
0
TONE 12
0
TONE 13
0
TONE 14
0
TONE 15
0
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 21

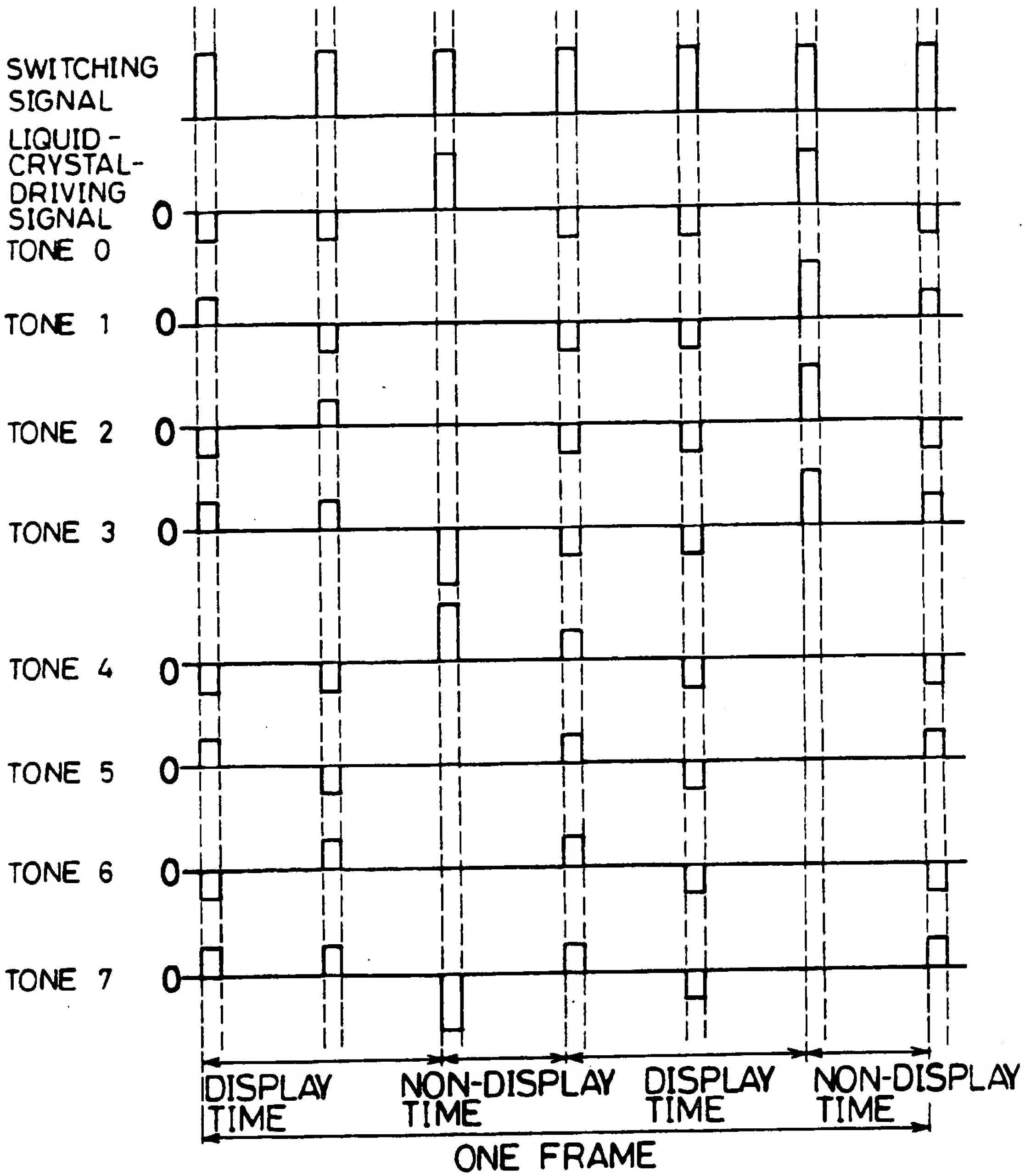

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0
TONE 1
TONE 2
TONE 3
TONE 4
TONE 5
TONE 6
TONE 7
0
DISPLAY TIME
NON-DISPLAY TIME
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 22

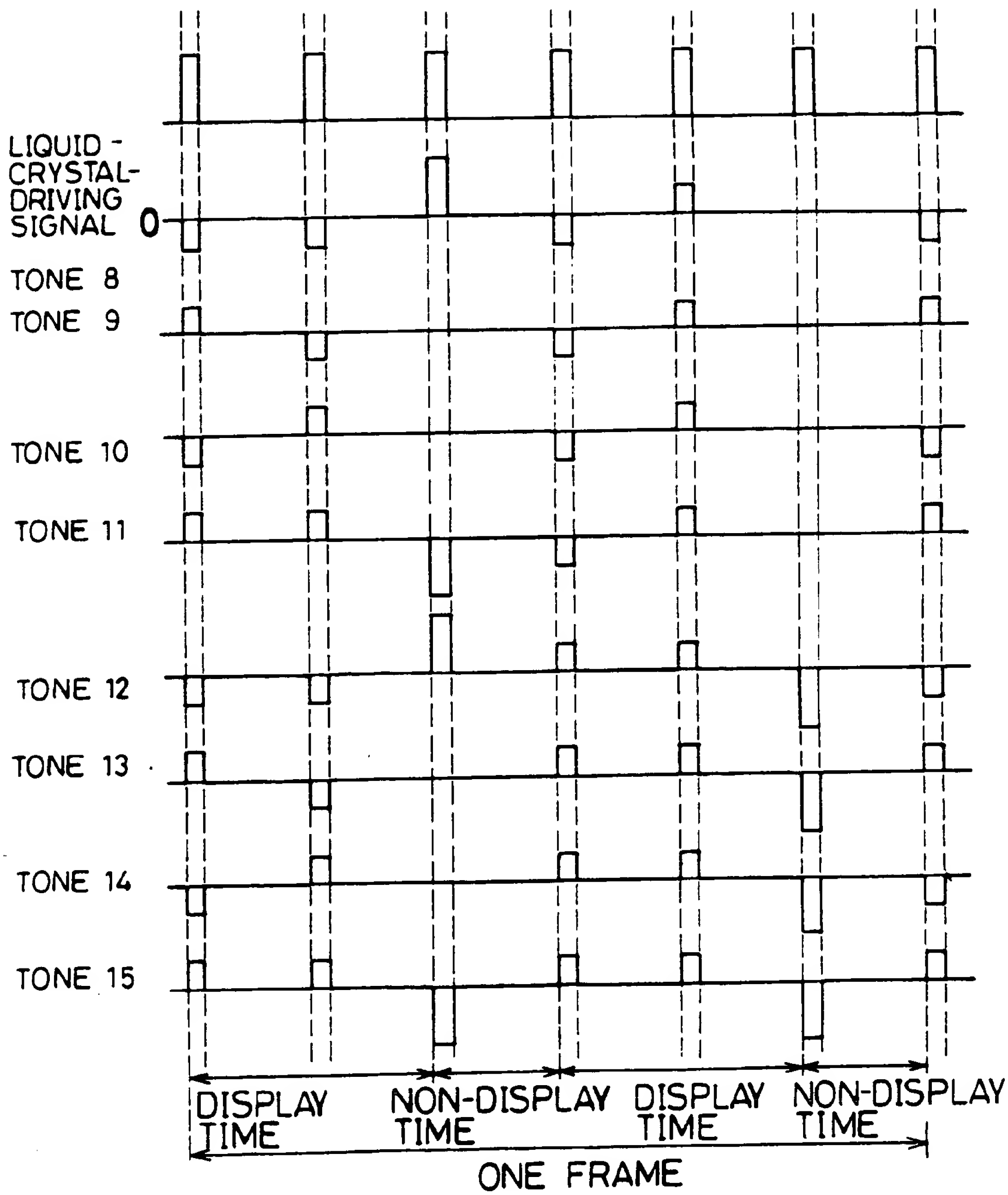

LIQUID - CRYSTAL- DRIVING SIGNAL
0
TONE 8
TONE 9
TONE 10
TONE 11
TONE 12
TONE 13
TONE 14
TONE 15
DISPLAY TIME
NON-DISPLAY TIME
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 23

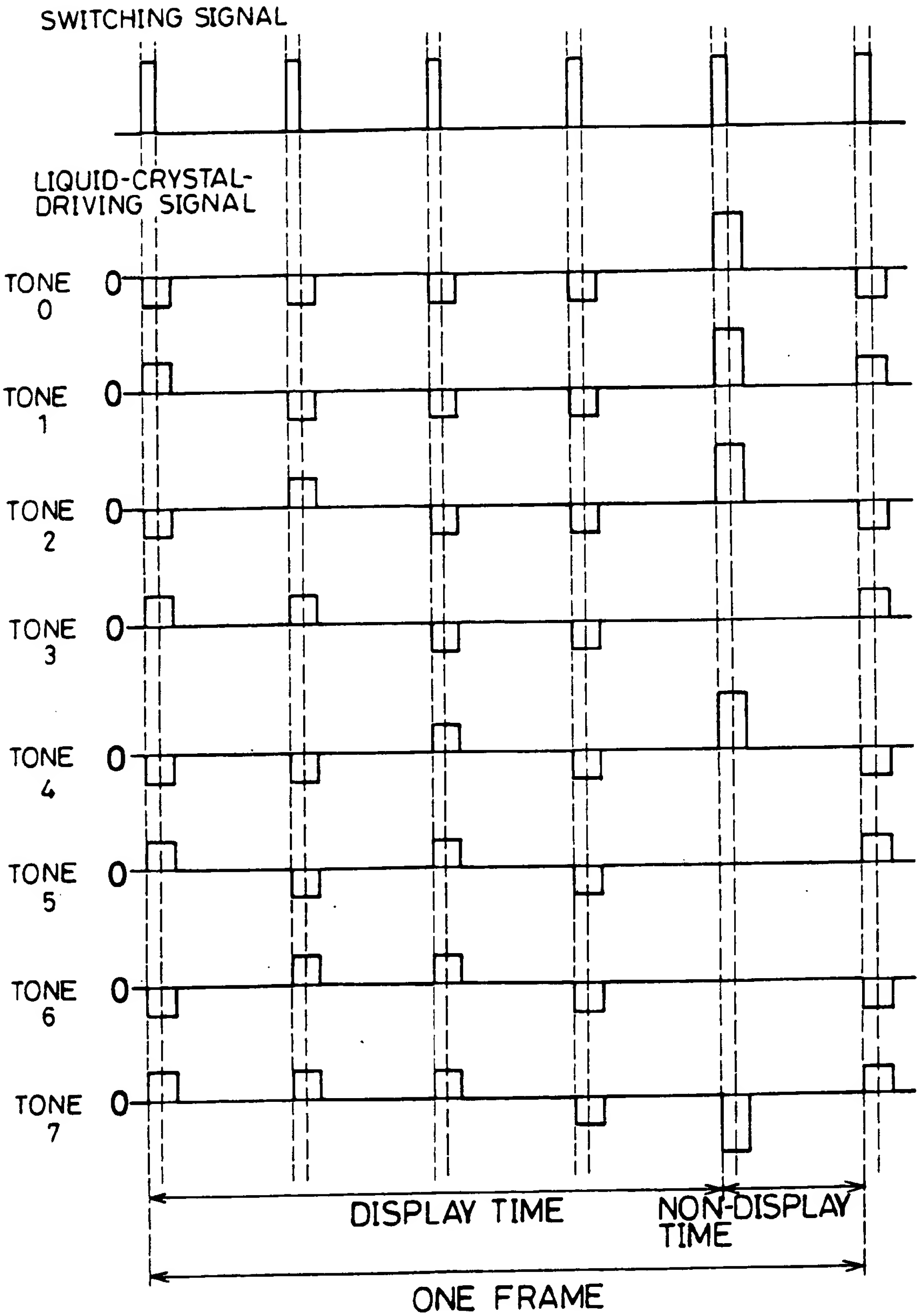

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0
TONE 1
TONE 2
TONE 3
TONE 4
TONE 5
TONE 6
TONE 7
0
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 24

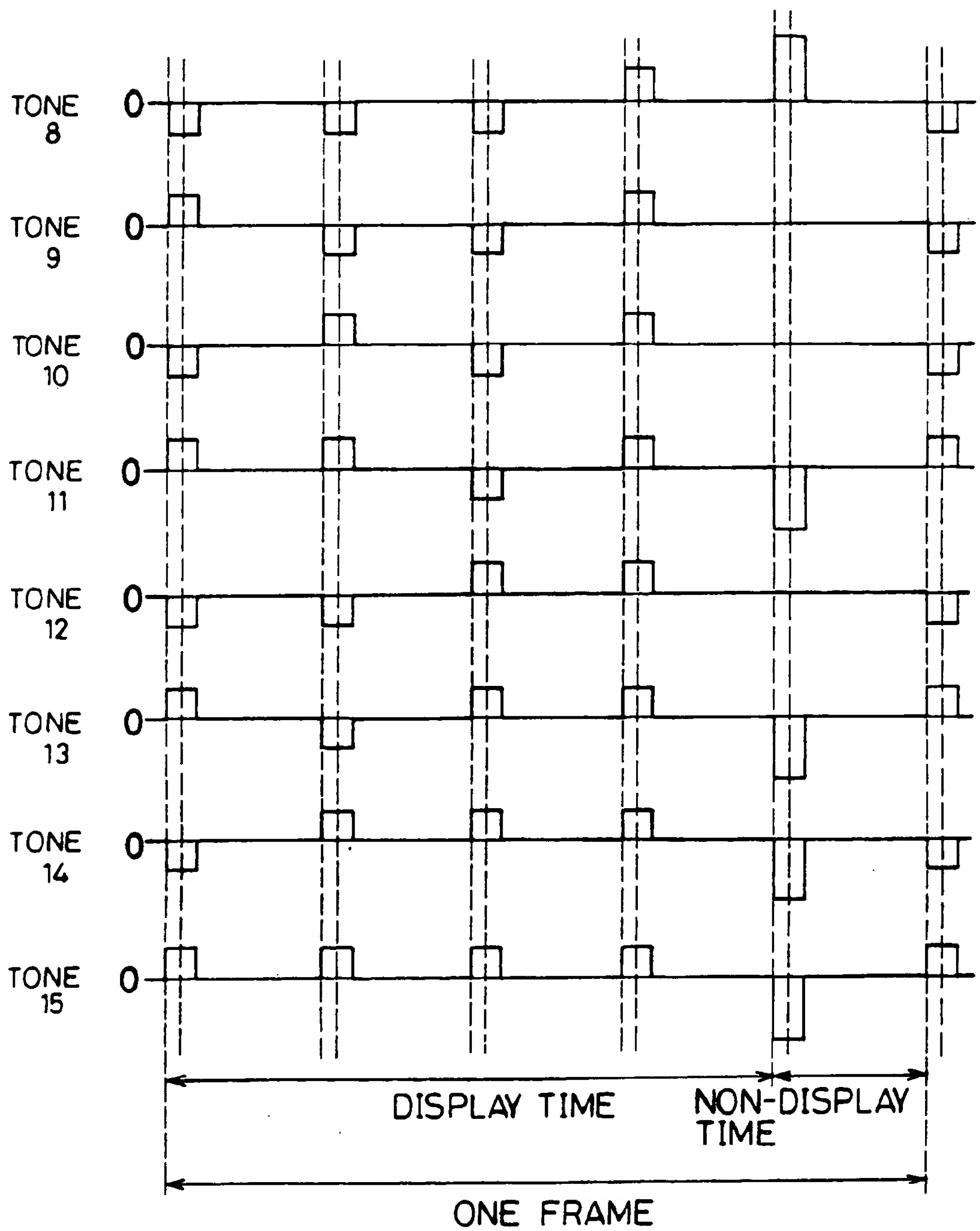

TONE 8
0
TONE 9
0
TONE 10
0
TONE 11
0
TONE 12
0
TONE 13
0
TONE 14
0
TONE 15
0
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 25

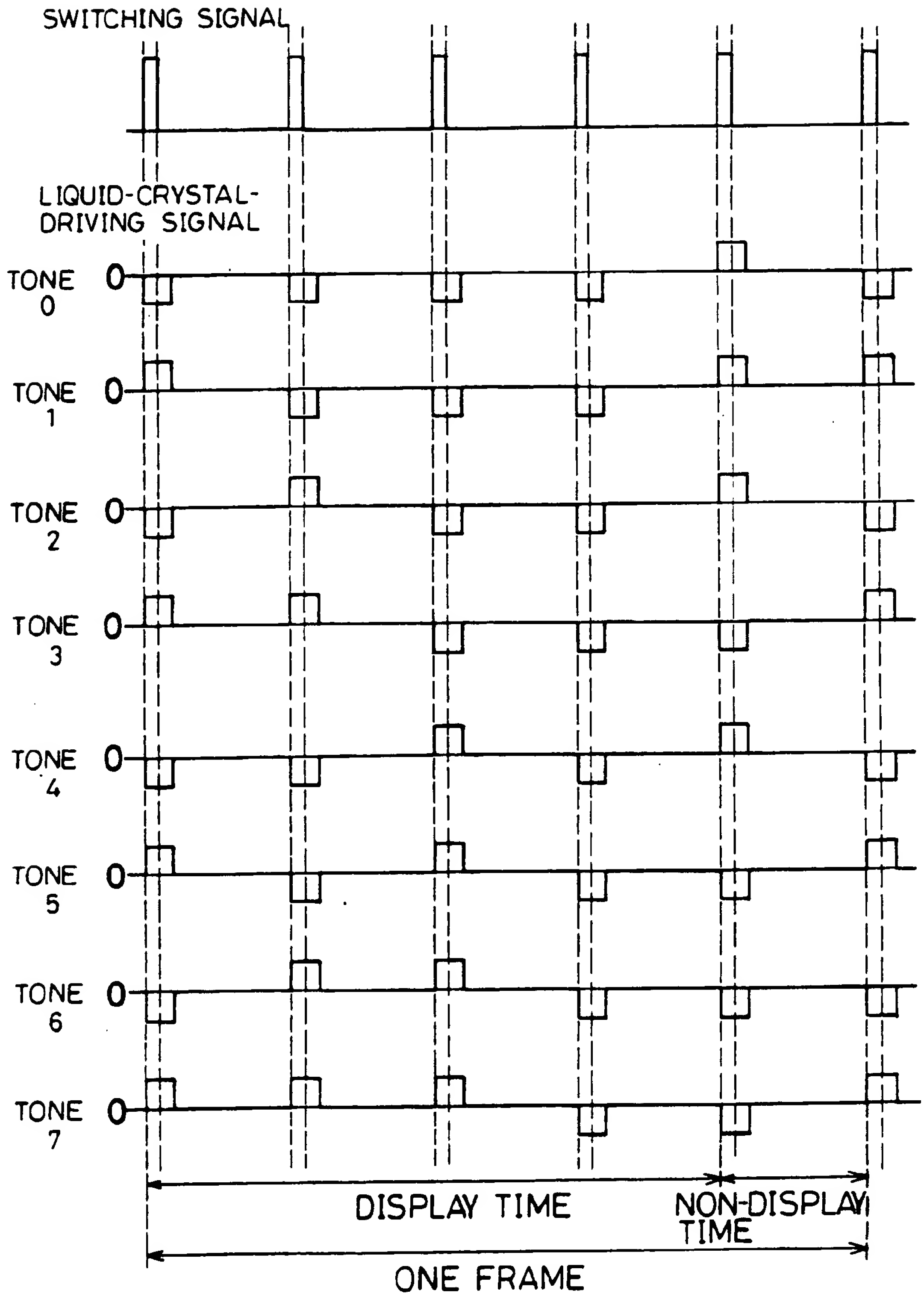

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0
TONE 1
TONE 2
TONE 3
TONE 4
TONE 5
TONE 6
TONE 7
0
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 26

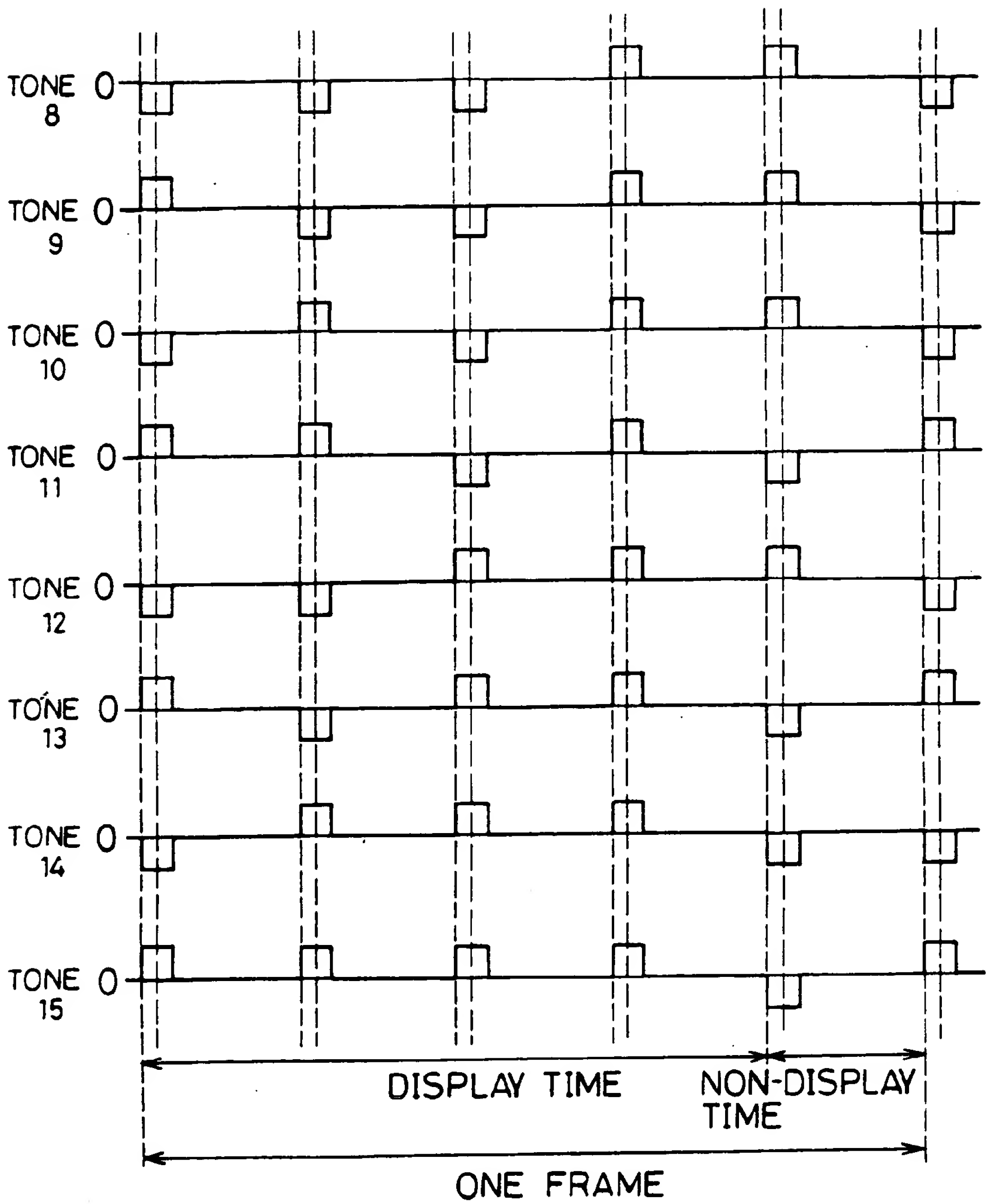

TONE 8
0
TONE 9
0
TONE 10
0
TONE 11
0
TONE 12
0
TONE 13
0
TONE 14
0
TONE 15
0
DISPLAY TIME
NON-DISPLAY TIME
ONE FRAME

FIG. 27

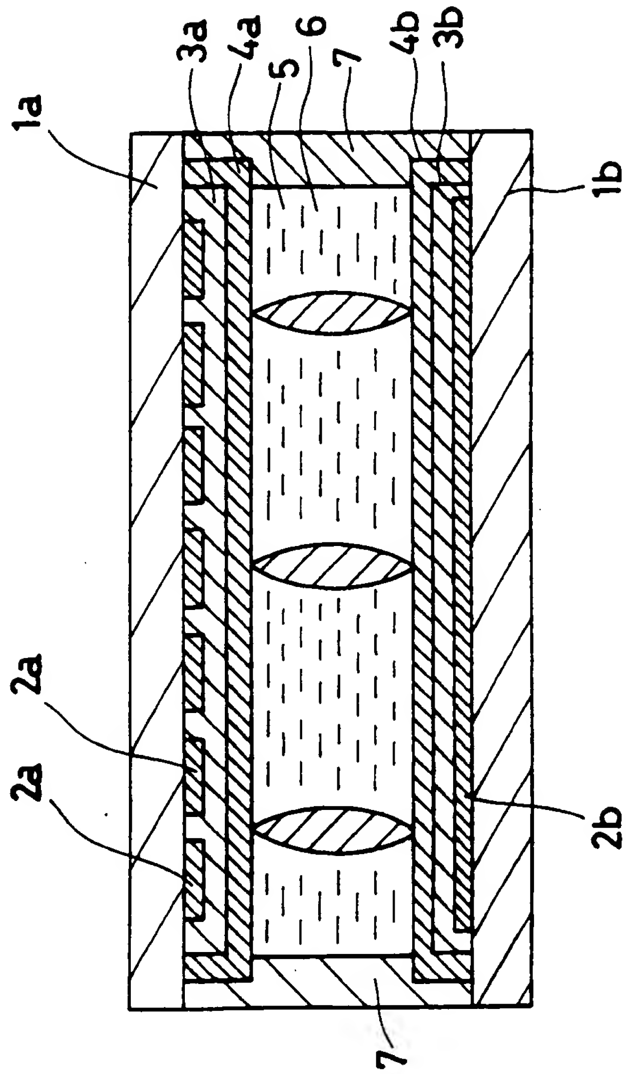


FIG. 28

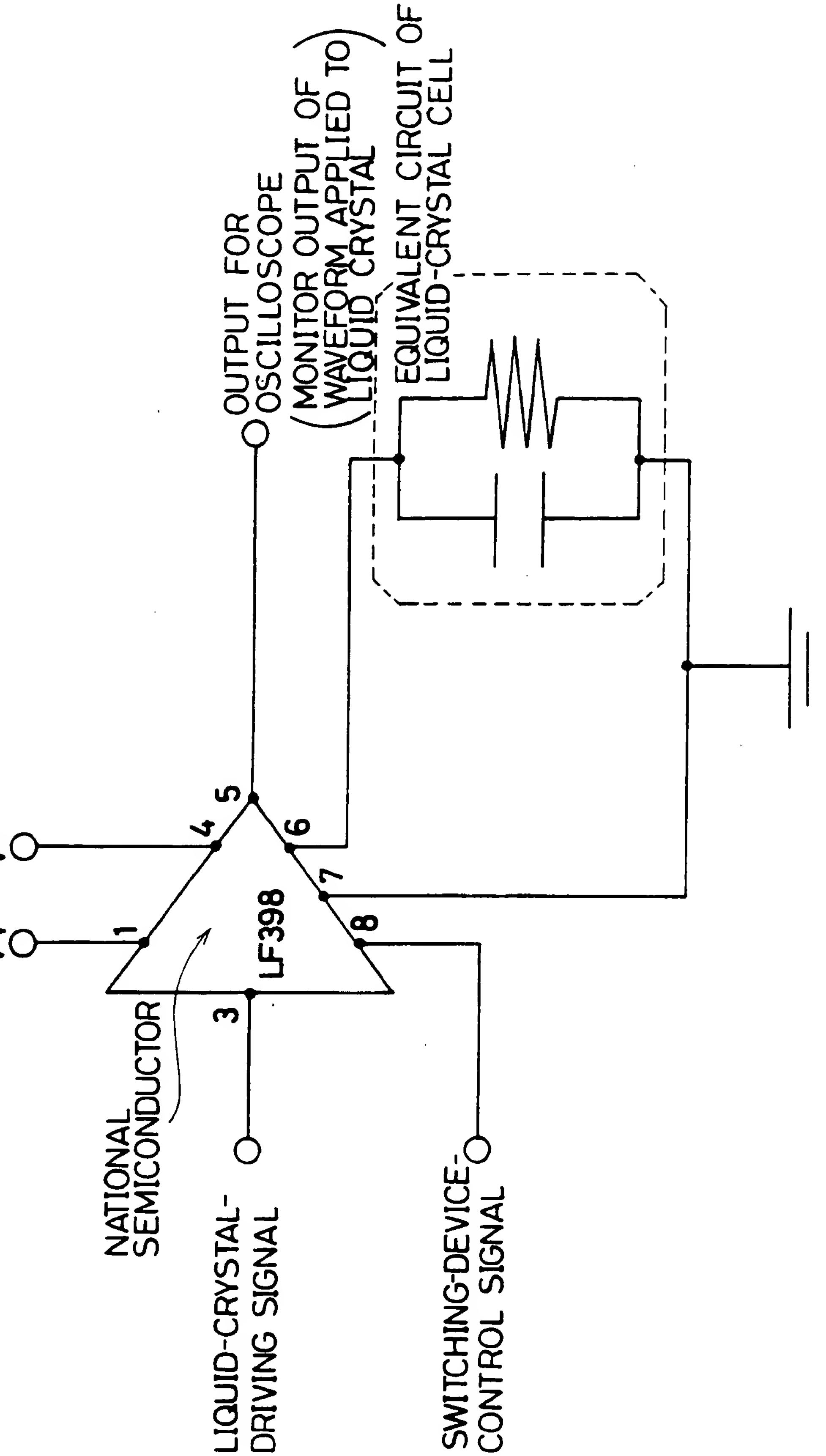

OUTPUT FOR OSCILLOSCOPE
(MONITOR OUTPUT OF WAVEFORM APPLIED TO LIQUID CRYSTAL)
EQUIVALENT CIRCUIT OF LIQUID-CRYSTAL CELL
V+
V-
1
3
4
5
6
7
8
LF398
NATIONAL SEMICONDUCTOR
LIQUID-CRYSTAL-DRIVING SIGNAL
SWITCHING-DEVICE-CONTROL SIGNAL

FIG. 29

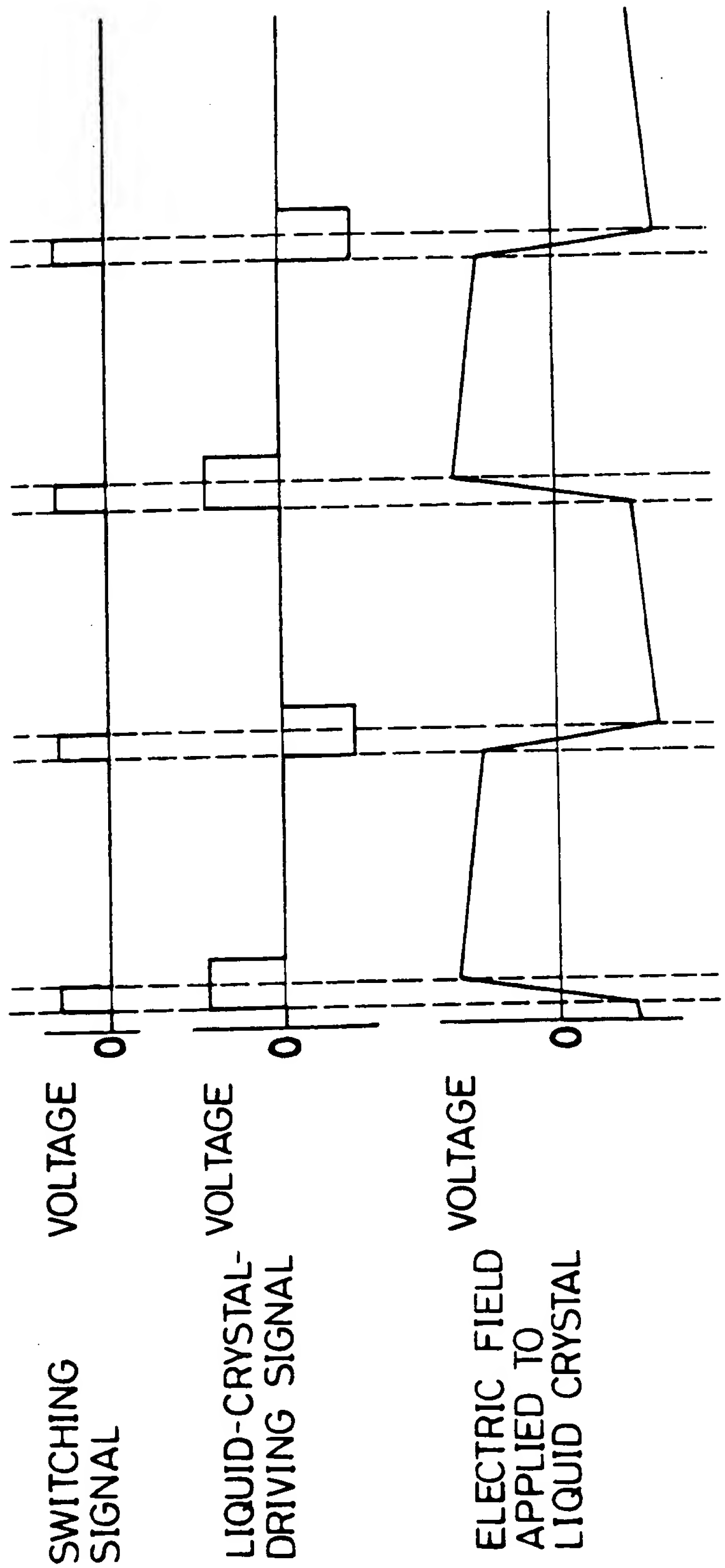

SWITCHING SIGNAL
VOLTAGE
0
LIQUID-CRYSTAL-DRIVING SIGNAL
VOLTAGE
0
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
VOLTAGE
0

FIG. 30

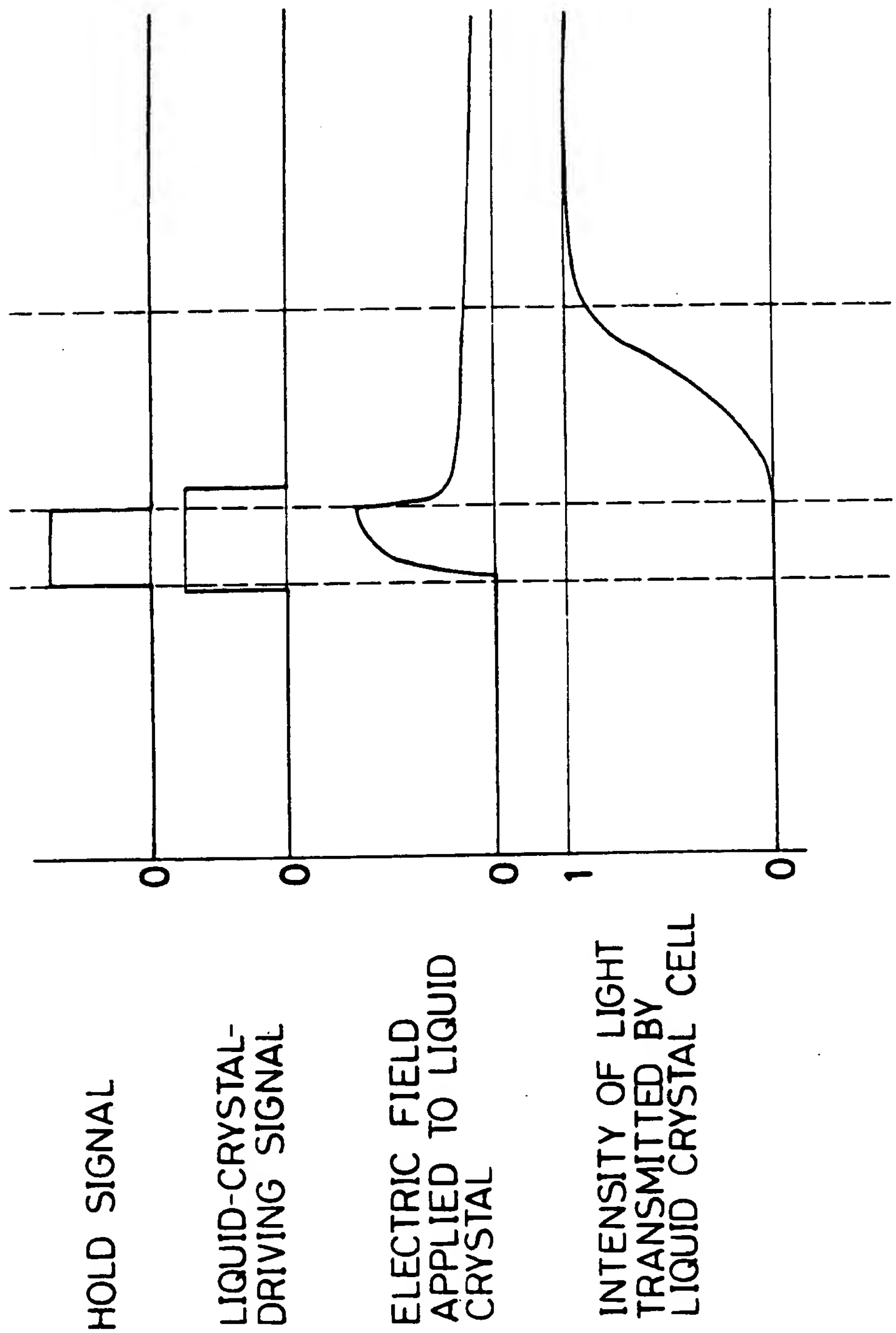

HOLD SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
INTENSITY OF LIGHT TRANSMITTED BY LIQUID CRYSTAL CELL
0
0
0
1
0

FIG. 31

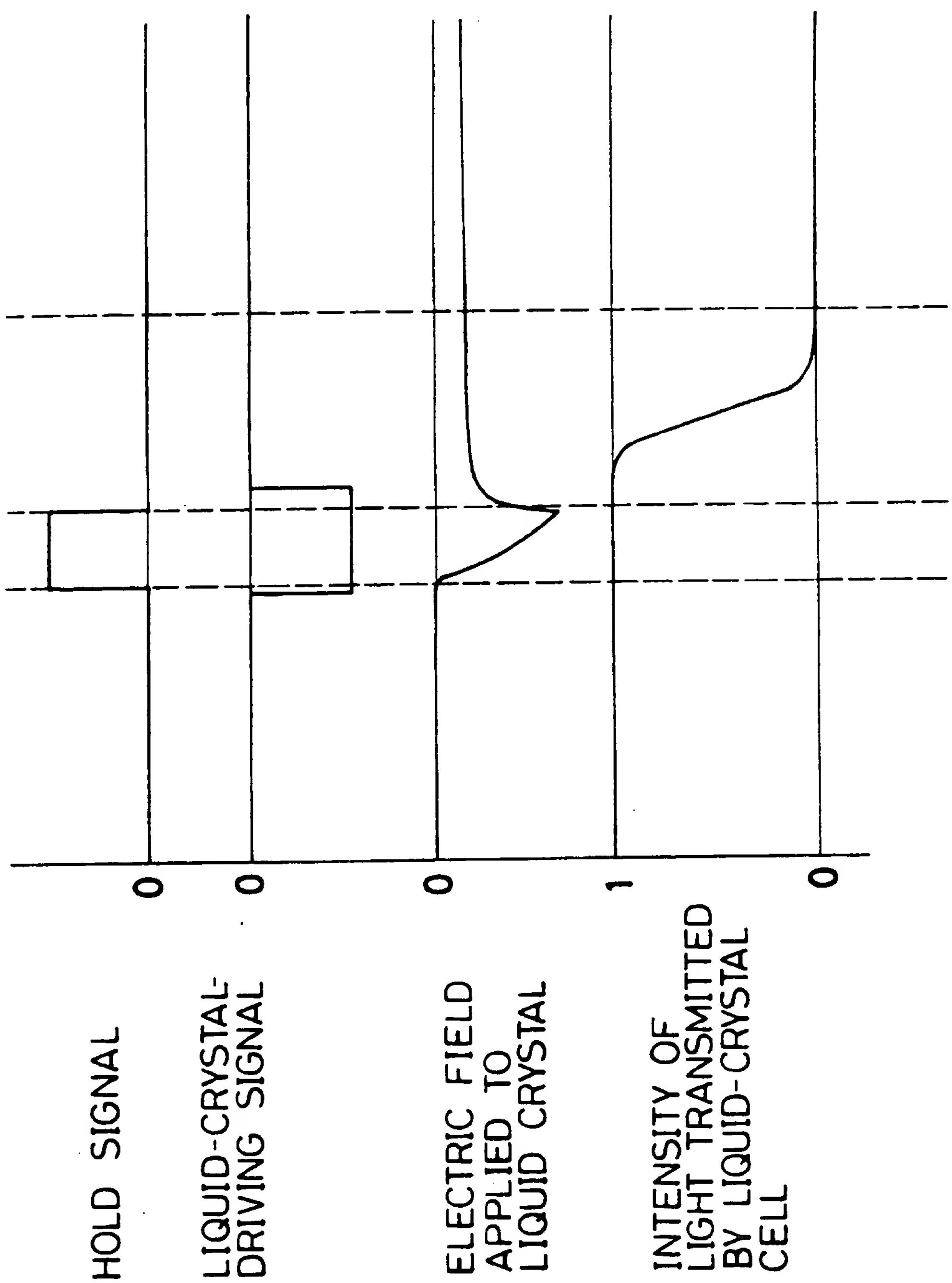

HOLD SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
INTENSITY OF LIGHT TRANSMITTED BY LIQUID-CRYSTAL CELL
0
0
0
1
0

FIG. 32

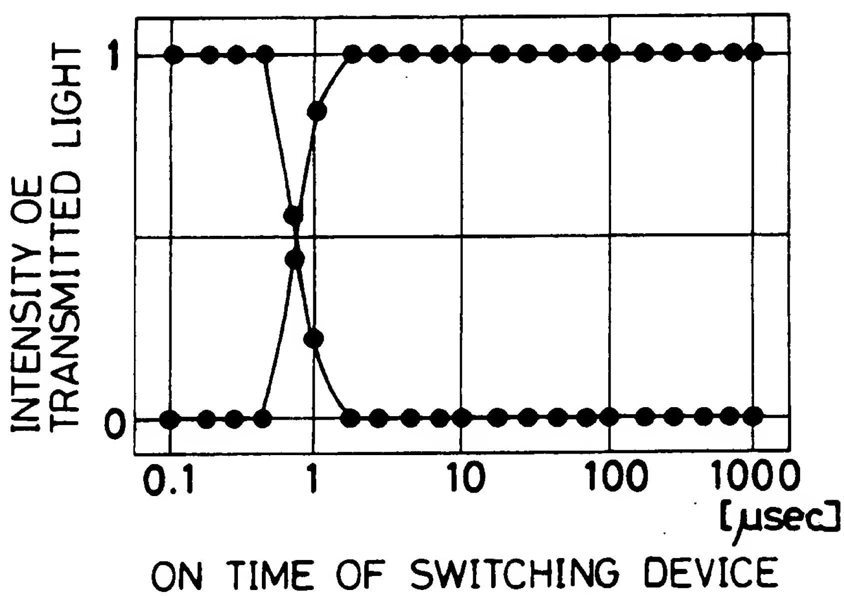

INTENSITY OE
TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
ON TIME OF SWITCHING DEVICE

FIG. 33

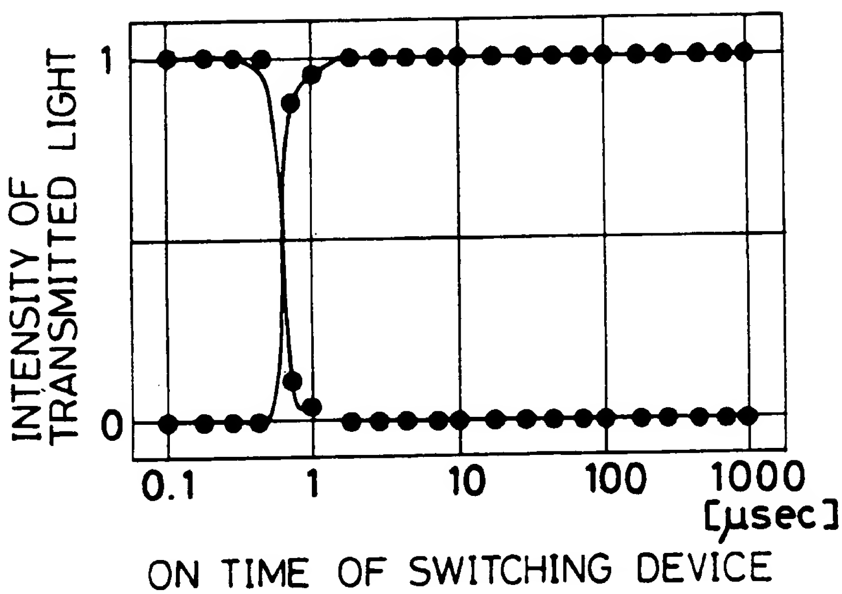

INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
ON TIME OF SWITCHING DEVICE

FIG. 34

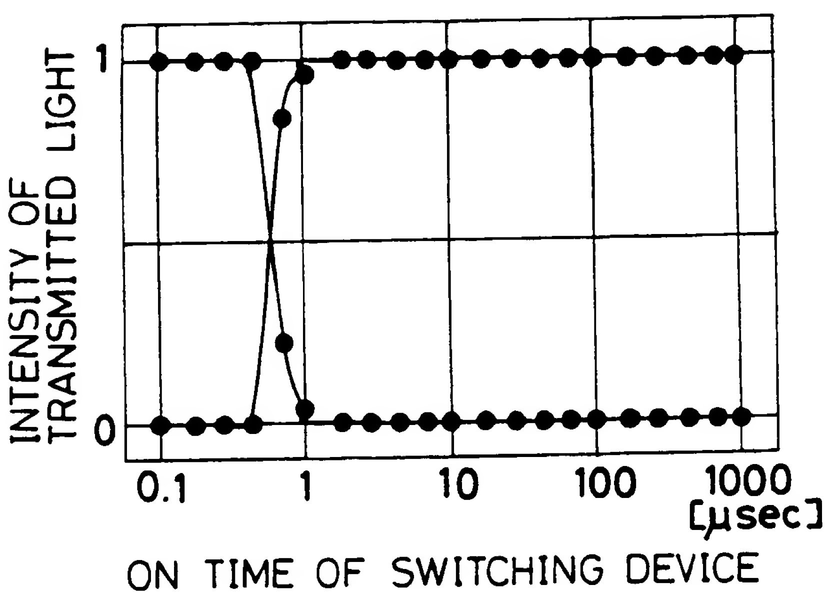

INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
ON TIME OF SWITCHING DEVICE

FIG. 35

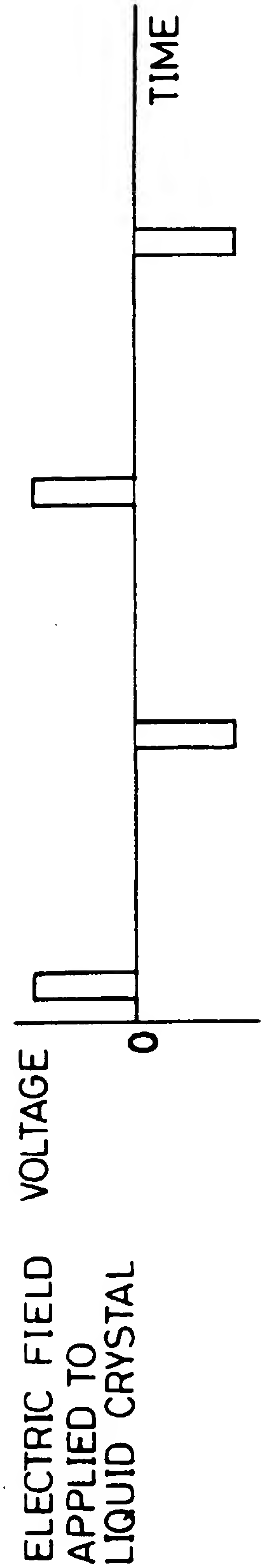


FIG. 36

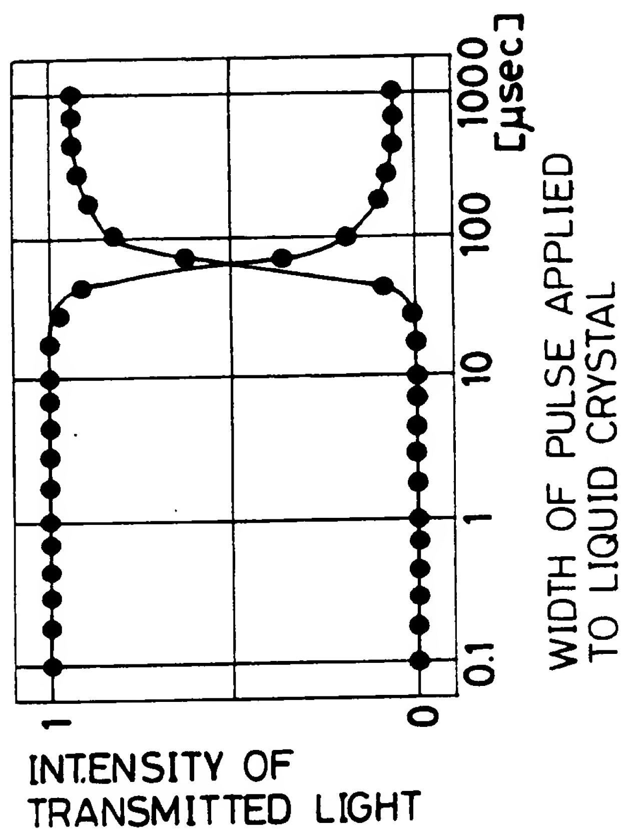

INTENSITY OF
TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
WIDTH OF PULSE APPLIED
TO LIQUID CRYSTAL

FIG. 37

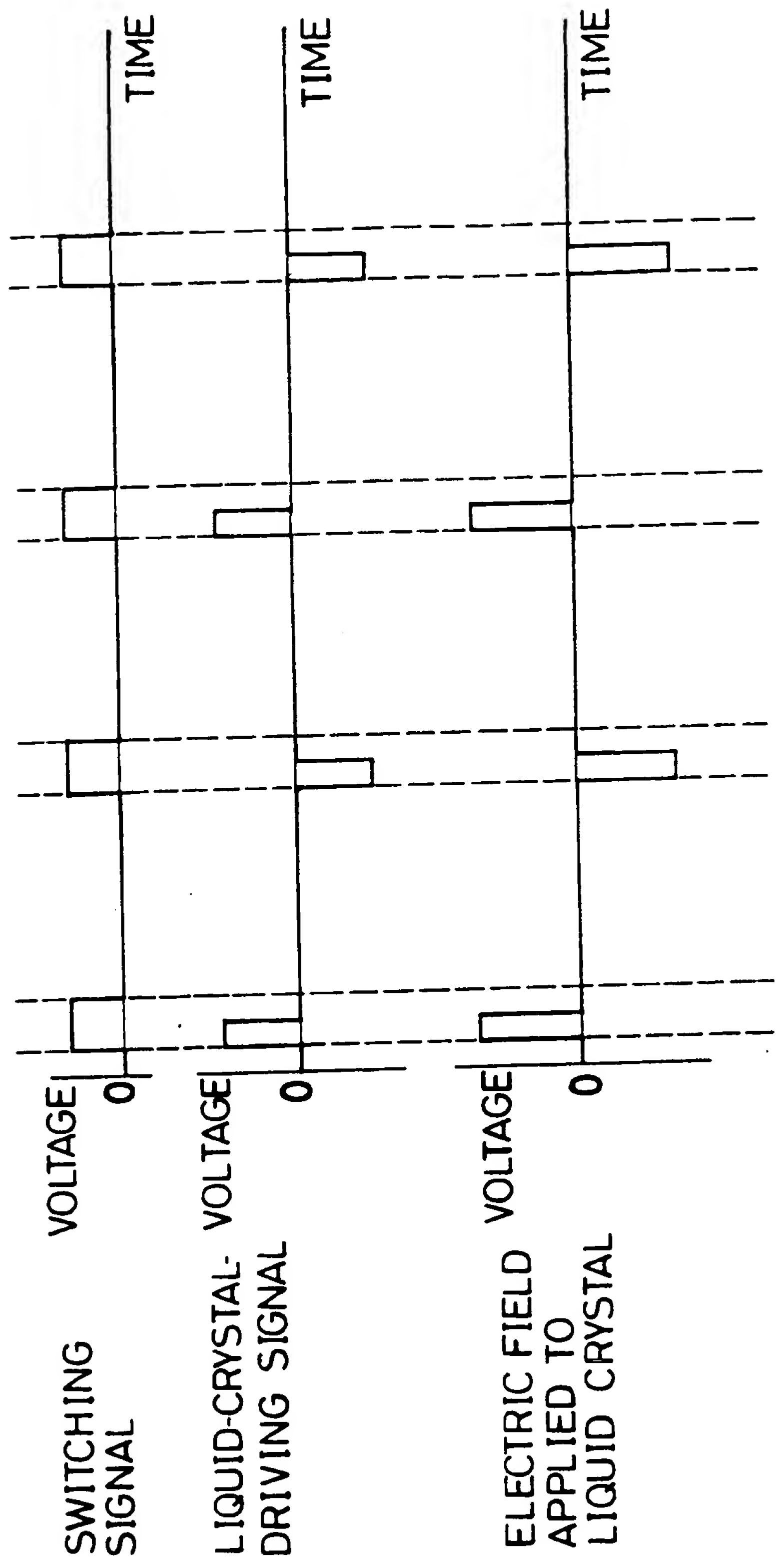
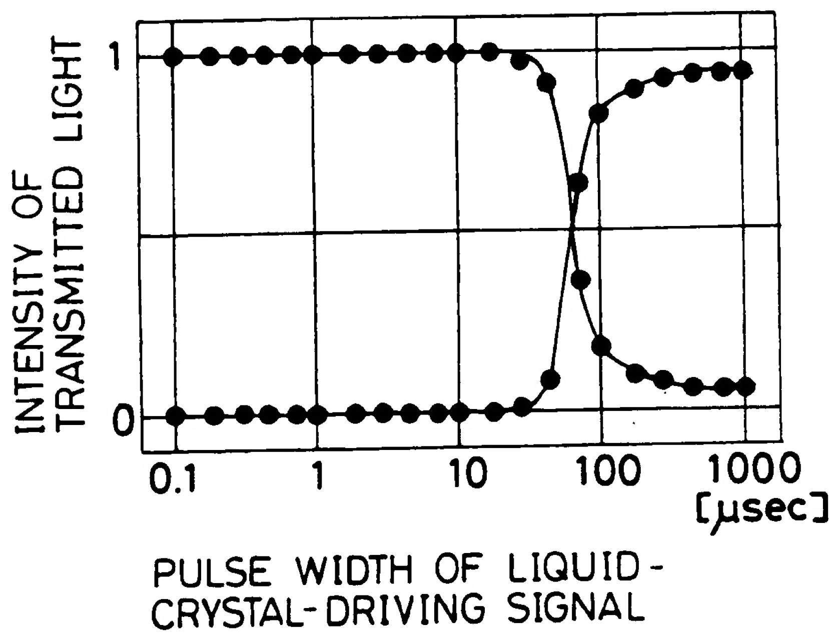

SWITCHING SIGNAL
VOLTAGE
0
TIME
LIQUID-CRYSTAL-DRIVING SIGNAL
VOLTAGE
0
TIME
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
VOLTAGE
0
TIME

FIG. 38



INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
PULSE WIDTH OF LIQUID-CRYSTAL-DRIVING SIGNAL

FIG. 39

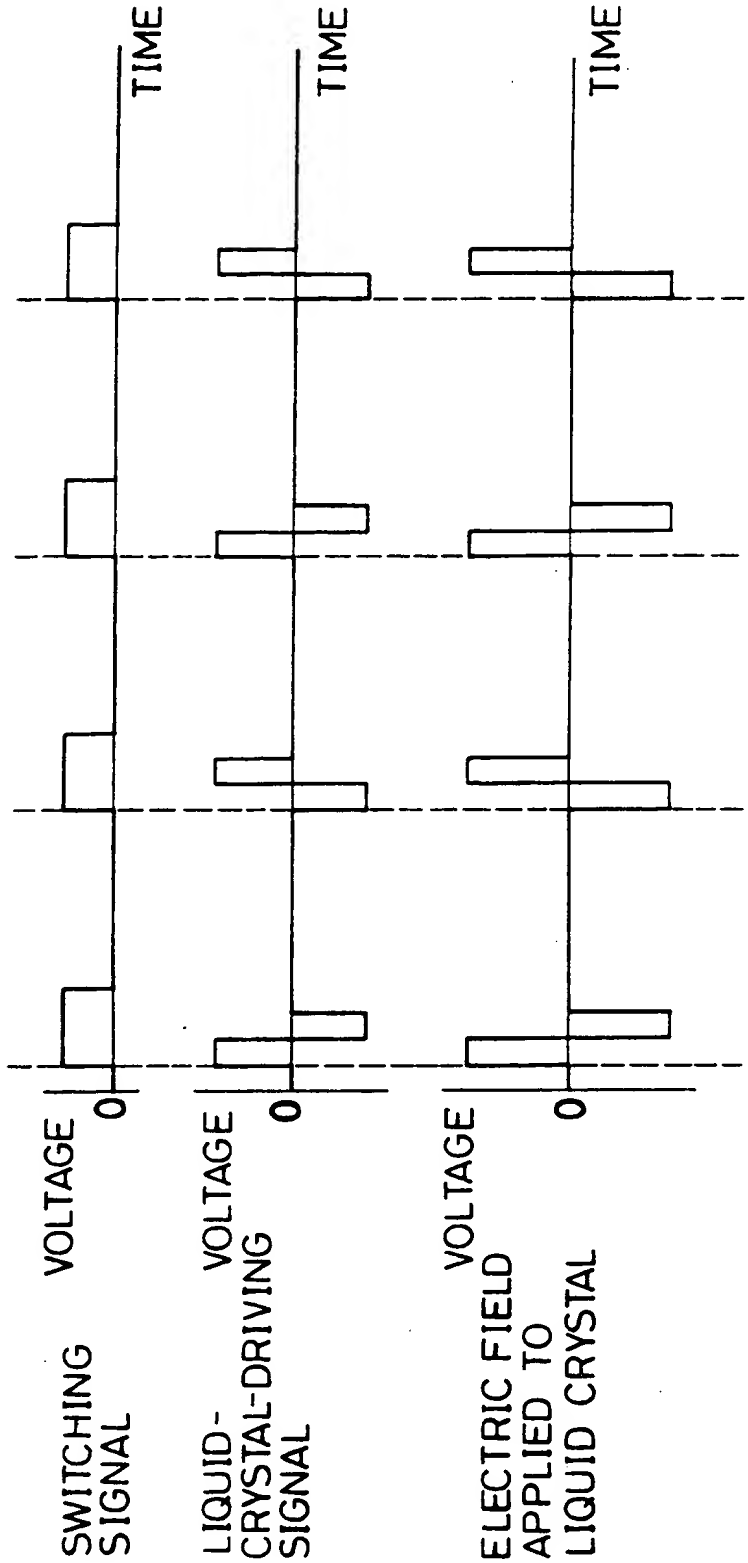

SWITCHING SIGNAL
VOLTAGE
0
TIME
LIQUID-CRYSTAL-DRIVING SIGNAL
VOLTAGE
0
TIME
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
VOLTAGE
0
TIME

FIG. 40

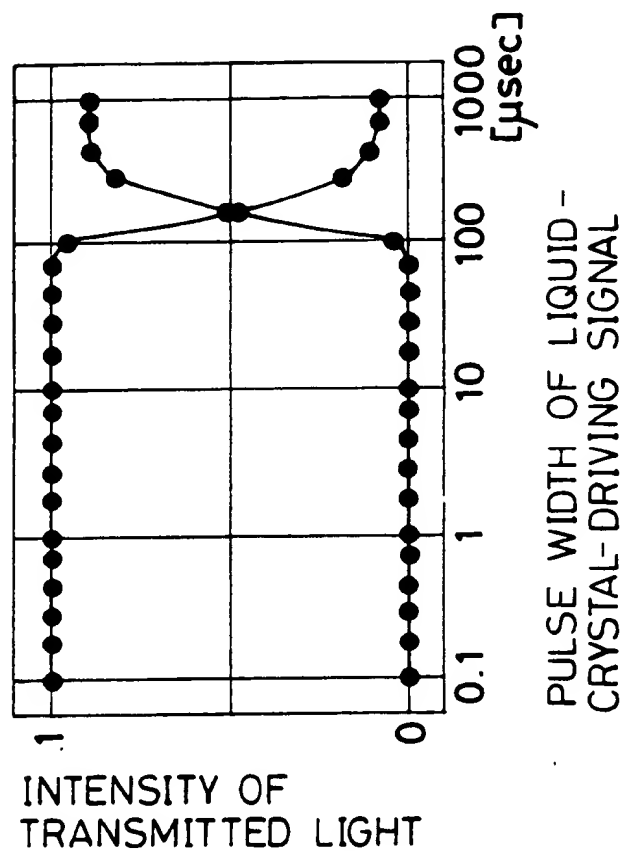

INTENSITY OF
TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
PULSE WIDTH OF LIQUID-
CRYSTAL-DRIVING SIGNAL

FIG. 41

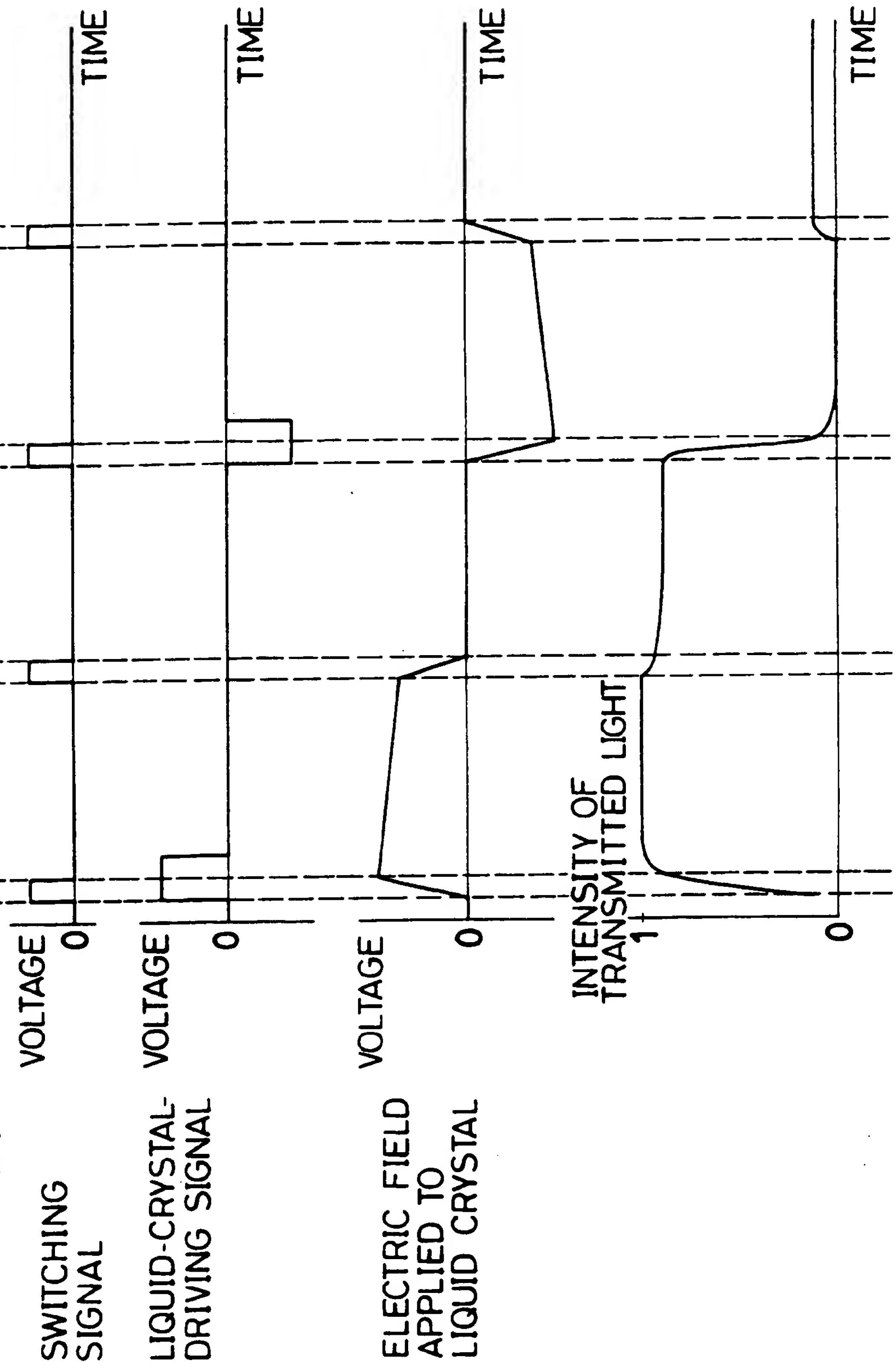
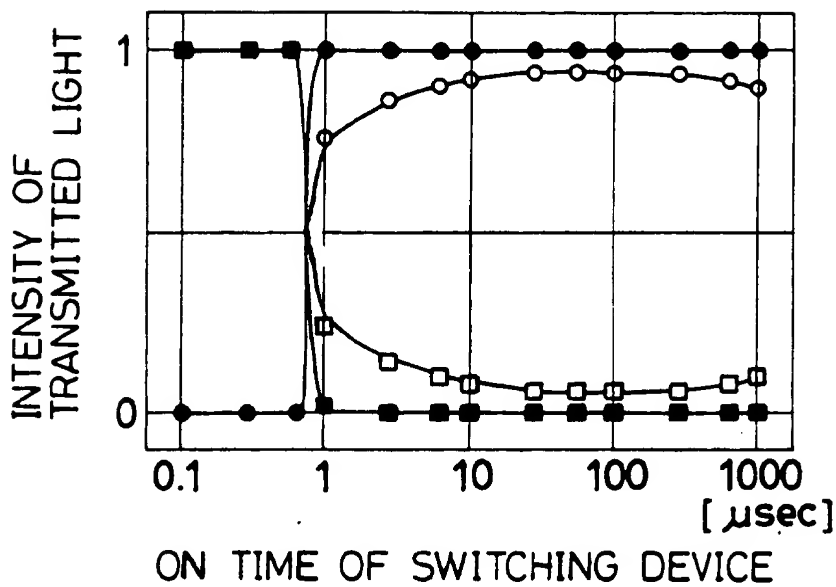

SWITCHING SIGNAL
VOLTAGE
0
TIME
LIQUID-CRYSTAL-DRIVING SIGNAL
VOLTAGE
0
TIME
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
VOLTAGE
0
TIME
INTENSITY OF TRANSMITTED LIGHT
1
0
TIME

FIG. 42



1
0
INTENSITY OF TRANSMITTED LIGHT
0.1
1
10
100
1000
[µsec]
ON TIME OF SWITCHING DEVICE

FIG. 43

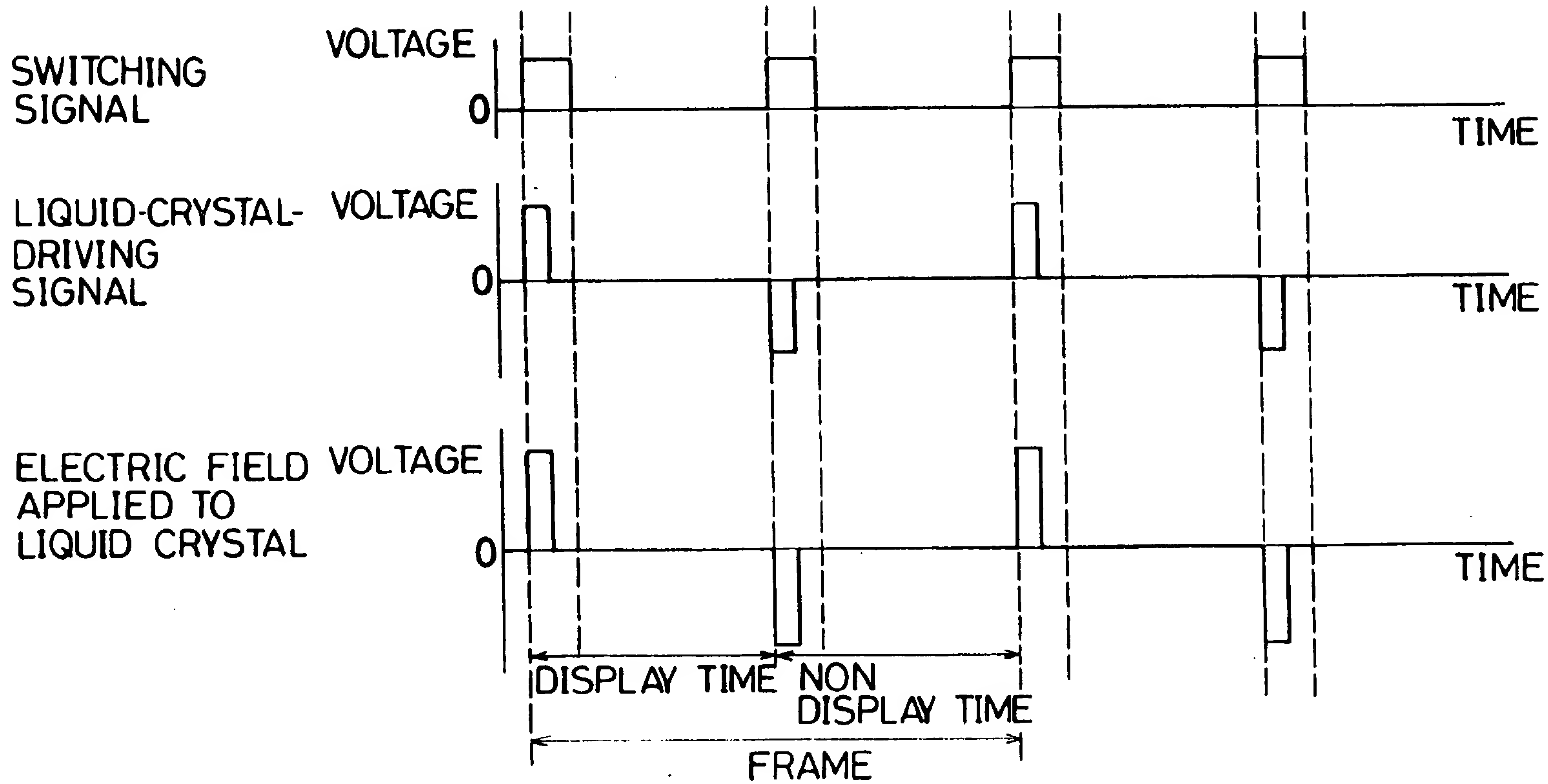
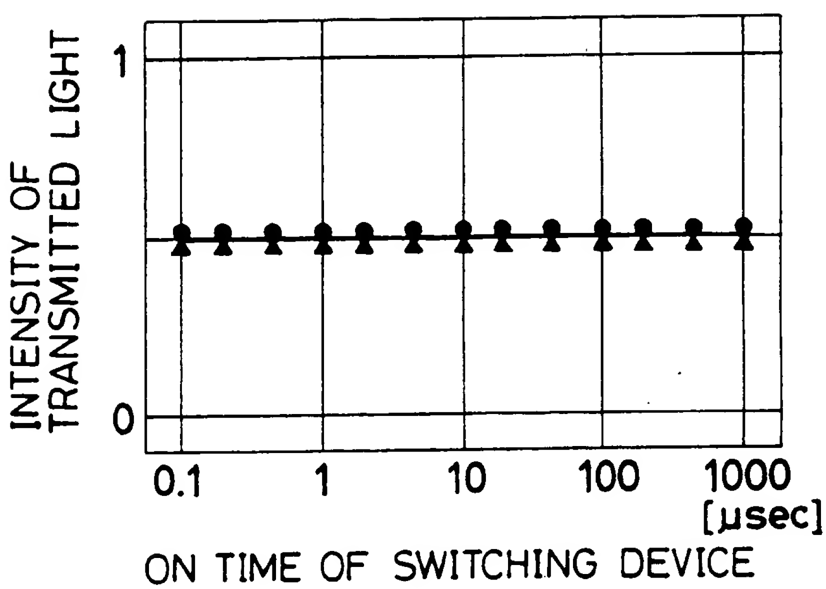

SWITCHING SIGNAL
VOLTAGE
0
TIME
LIQUID-CRYSTAL-DRIVING SIGNAL
VOLTAGE
0
TIME
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
VOLTAGE
0
TIME
DISPLAY TIME
NON DISPLAY TIME
FRAME

FIG. 44


INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
ON TIME OF SWITCHING DEVICE

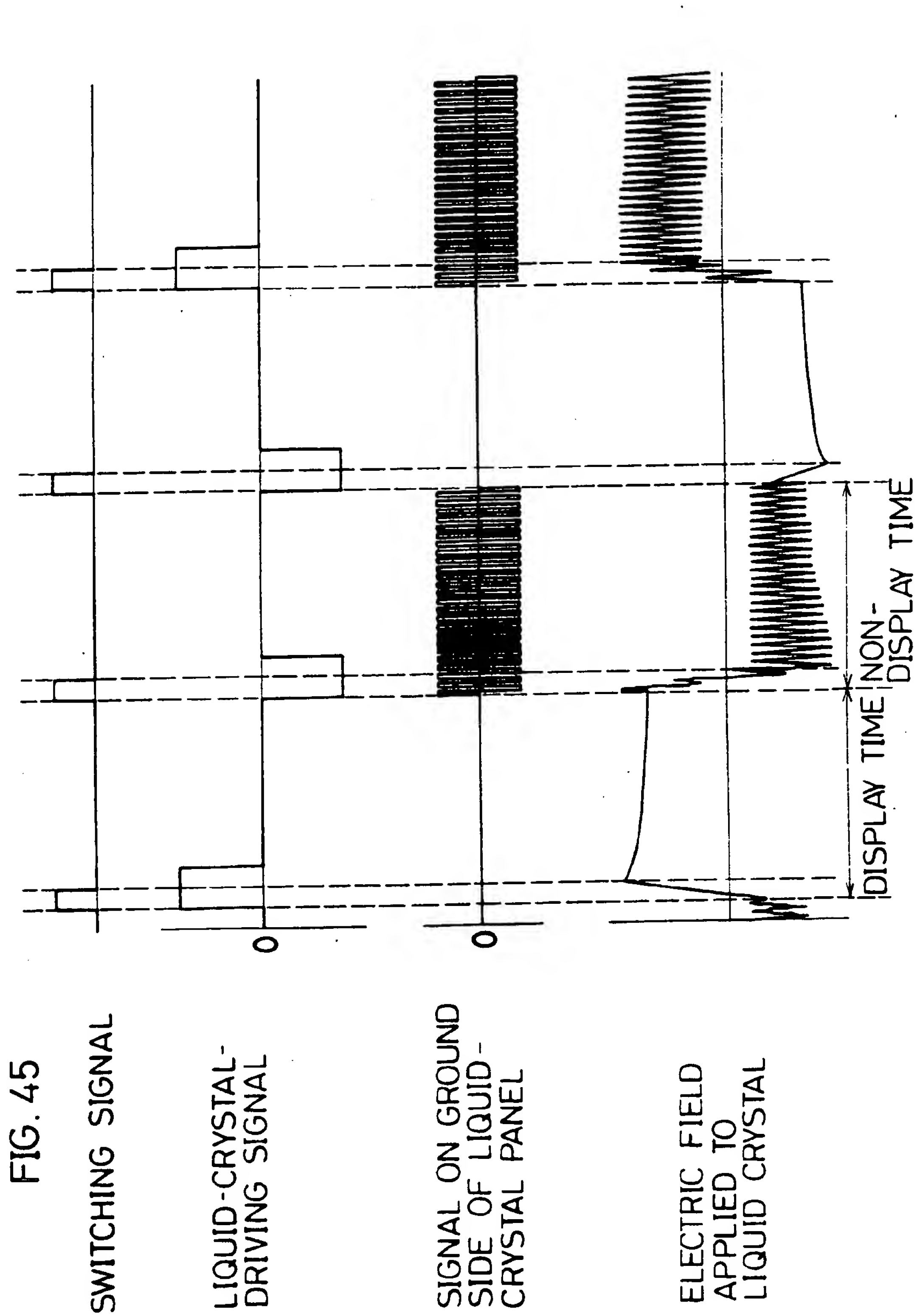

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
0
SIGNAL ON GROUND SIDE OF LIQUID-CRYSTAL PANEL
0
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
DISPLAY TIME
NON-DISPLAY TIME

FIG. 45

FIG. 46

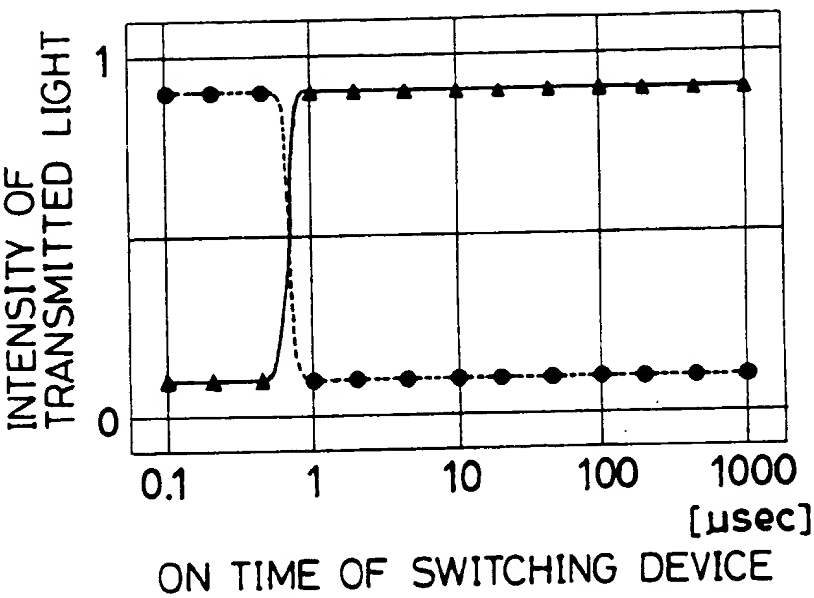

INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[µsec]
ON TIME OF SWITCHING DEVICE

FIG. 47

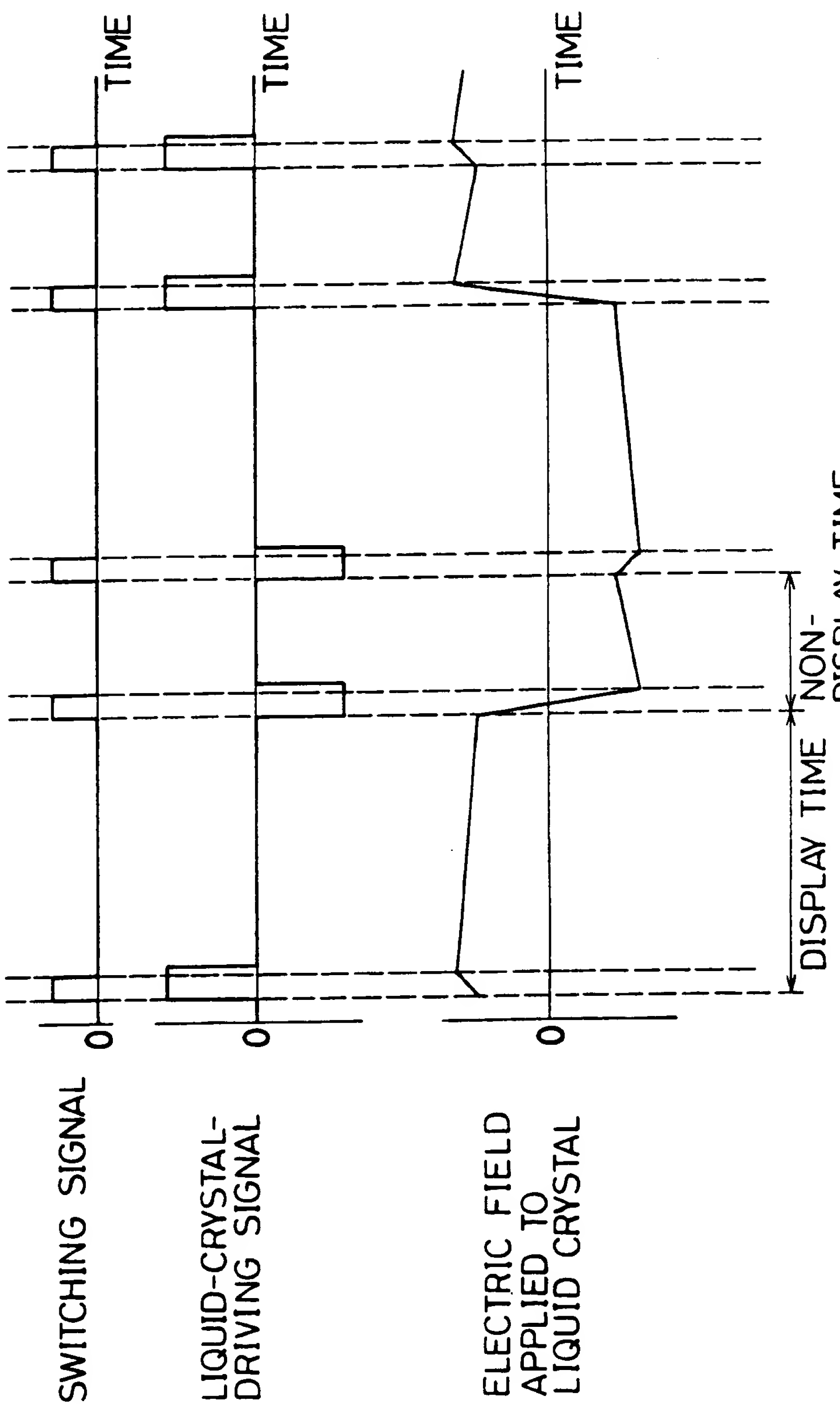

SWITCHING SIGNAL
LIQUID-CRYSTAL-DRIVING SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
0
0
0
TIME
TIME
TIME
DISPLAY TIME
NON-DISPLAY TIME

FIG. 48

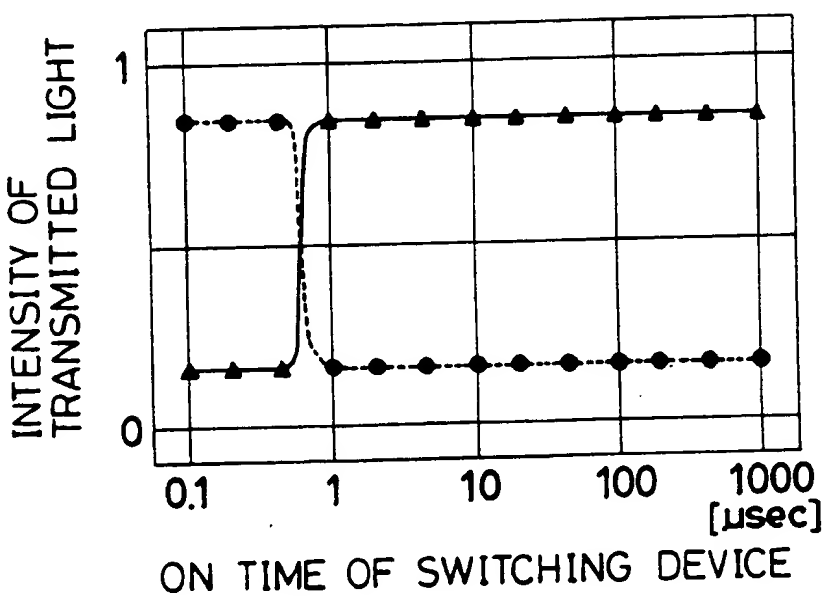

INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
ON TIME OF SWITCHING DEVICE

FIG. 49

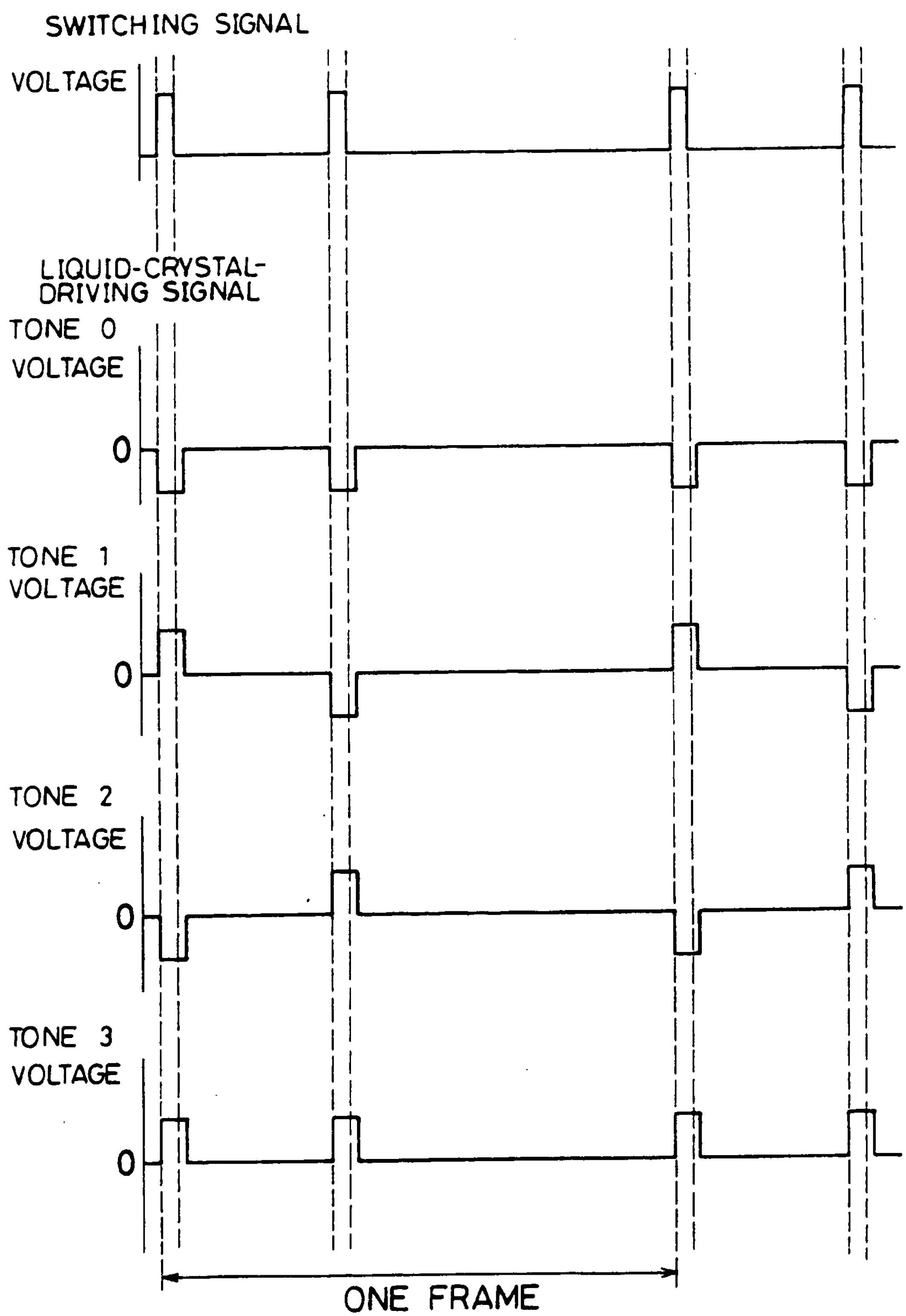

SWITCHING SIGNAL
VOLTAGE
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0
VOLTAGE
0
TONE 1
VOLTAGE
0
TONE 2
VOLTAGE
0
TONE 3
VOLTAGE
0
ONE FRAME

FIG. 50

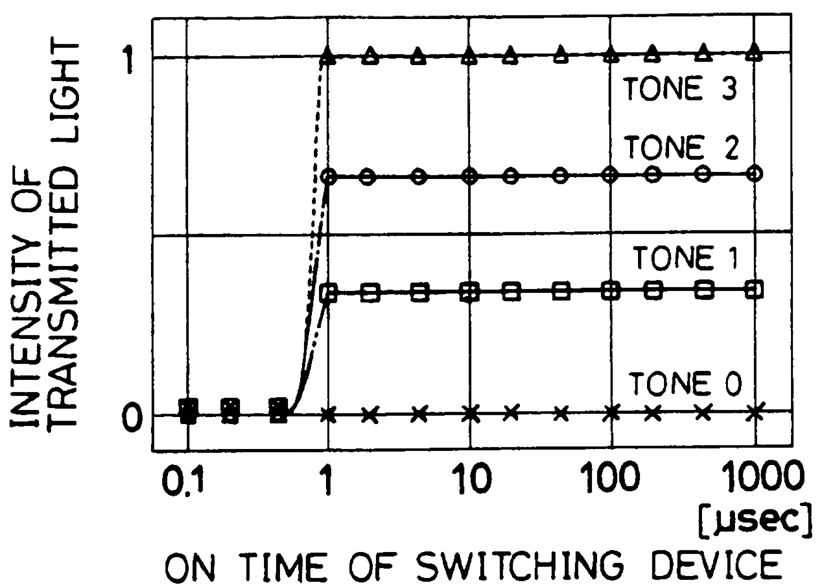

INTENSITY OF TRANSMITTED LIGHT
1
0
TONE 3
TONE 2
TONE 1
TONE 0
0.1
1
10
100
1000
[μsec]
ON TIME OF SWITCHING DEVICE

FIG. 51

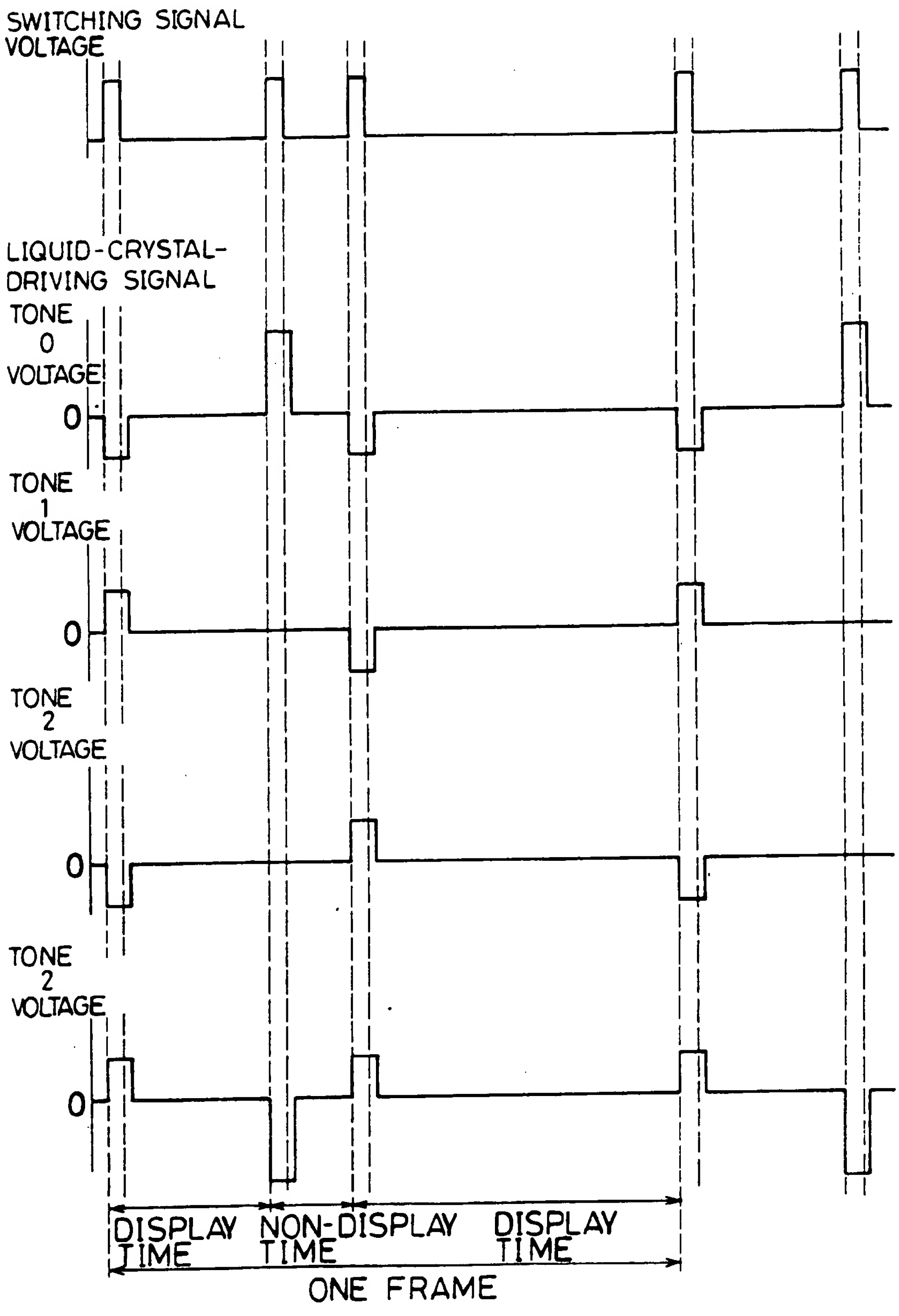

SWITCHING SIGNAL VOLTAGE
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0 VOLTAGE
0
TONE 1 VOLTAGE
0
TONE 2 VOLTAGE
0
TONE 2 VOLTAGE
0
DISPLAY TIME
NON-DISPLAY TIME
DISPLAY TIME
ONE FRAME

FIG. 52

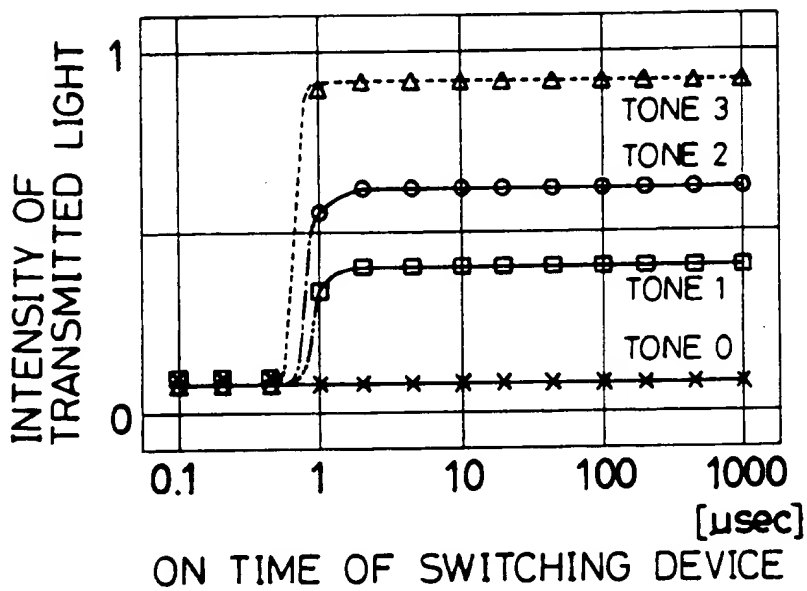

INTENSITY OF
TRANSMITTED LIGHT
1
0
TONE 3
TONE 2
TONE 1
TONE 0
0.1
1
10
100
1000
[µsec]
ON TIME OF SWITCHING DEVICE

FIG. 53

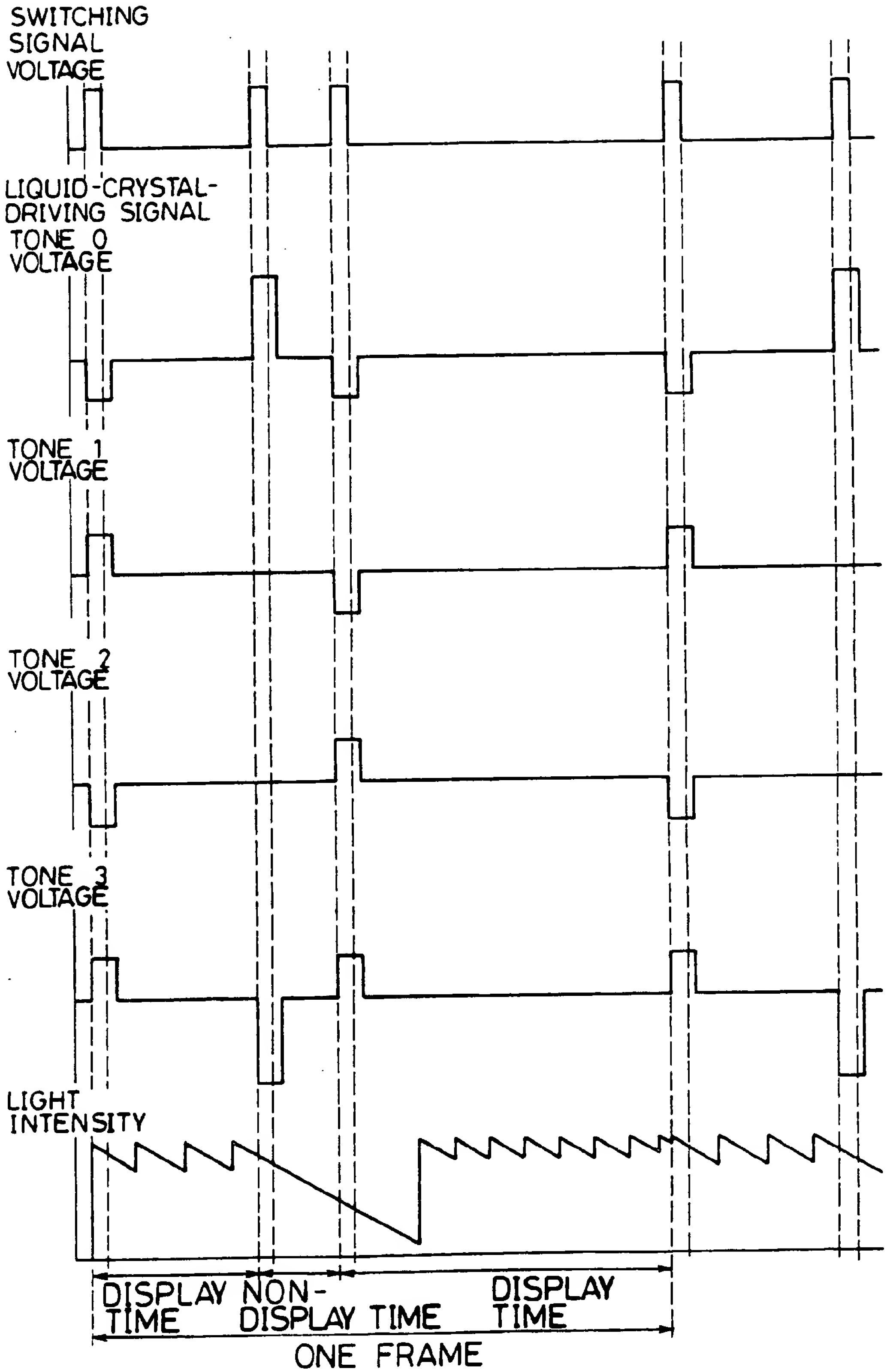

SWITCHING SIGNAL VOLTAGE
LIQUID-CRYSTAL-DRIVING SIGNAL
TONE 0 VOLTAGE
TONE 1 VOLTAGE
TONE 2 VOLTAGE
TONE 3 VOLTAGE
LIGHT INTENSITY
DISPLAY TIME
NON-DISPLAY TIME
DISPLAY TIME
ONE FRAME

FIG. 54

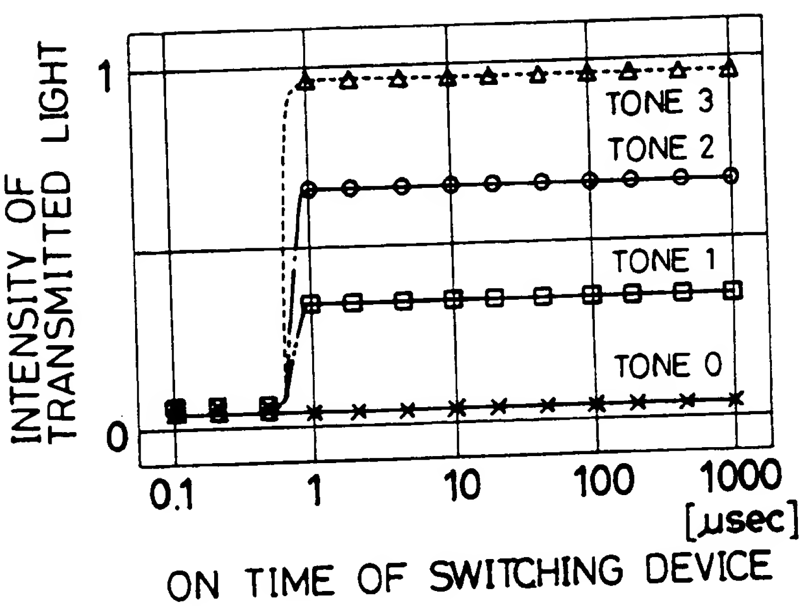

INTENSITY OF TRANSMITTED LIGHT
1
0
TONE 3
TONE 2
TONE 1
TONE 0
0.1
1
10
100
1000
[µsec]
ON TIME OF SWITCHING DEVICE

FIG. 55

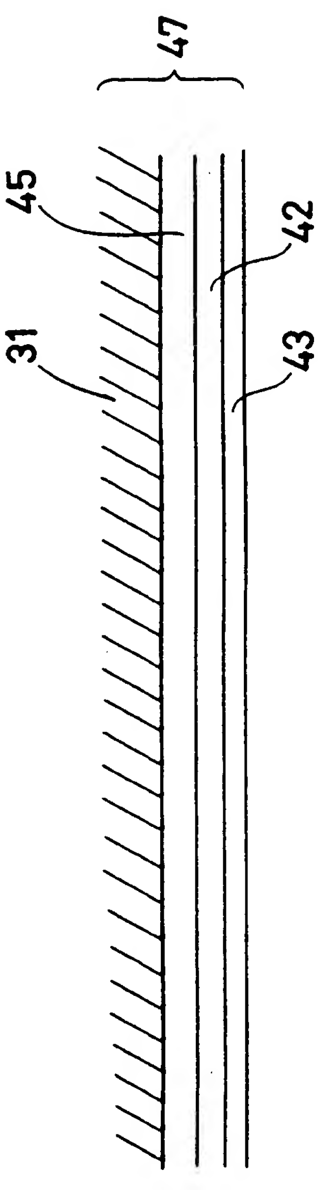
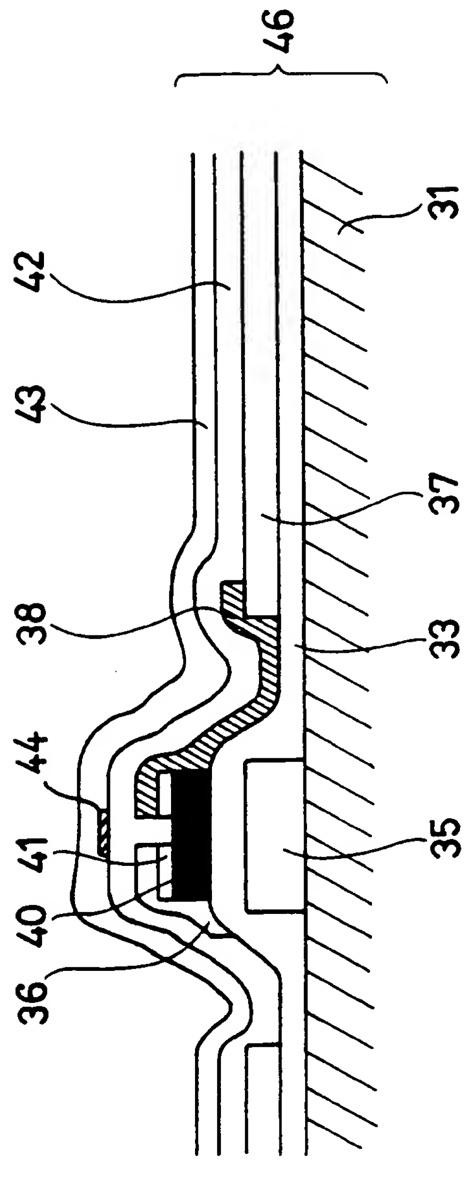


FIG. 56



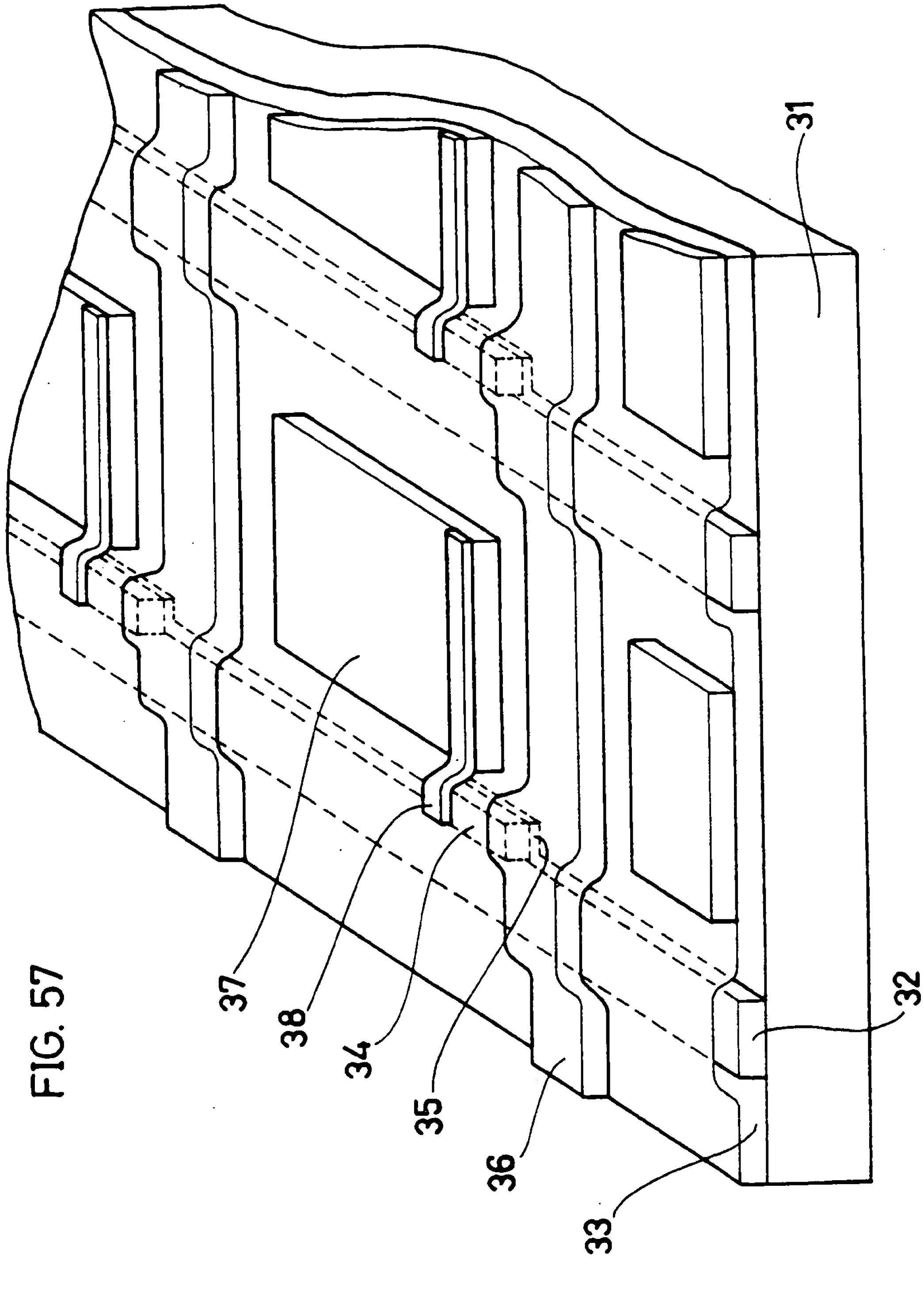


FIG. 57

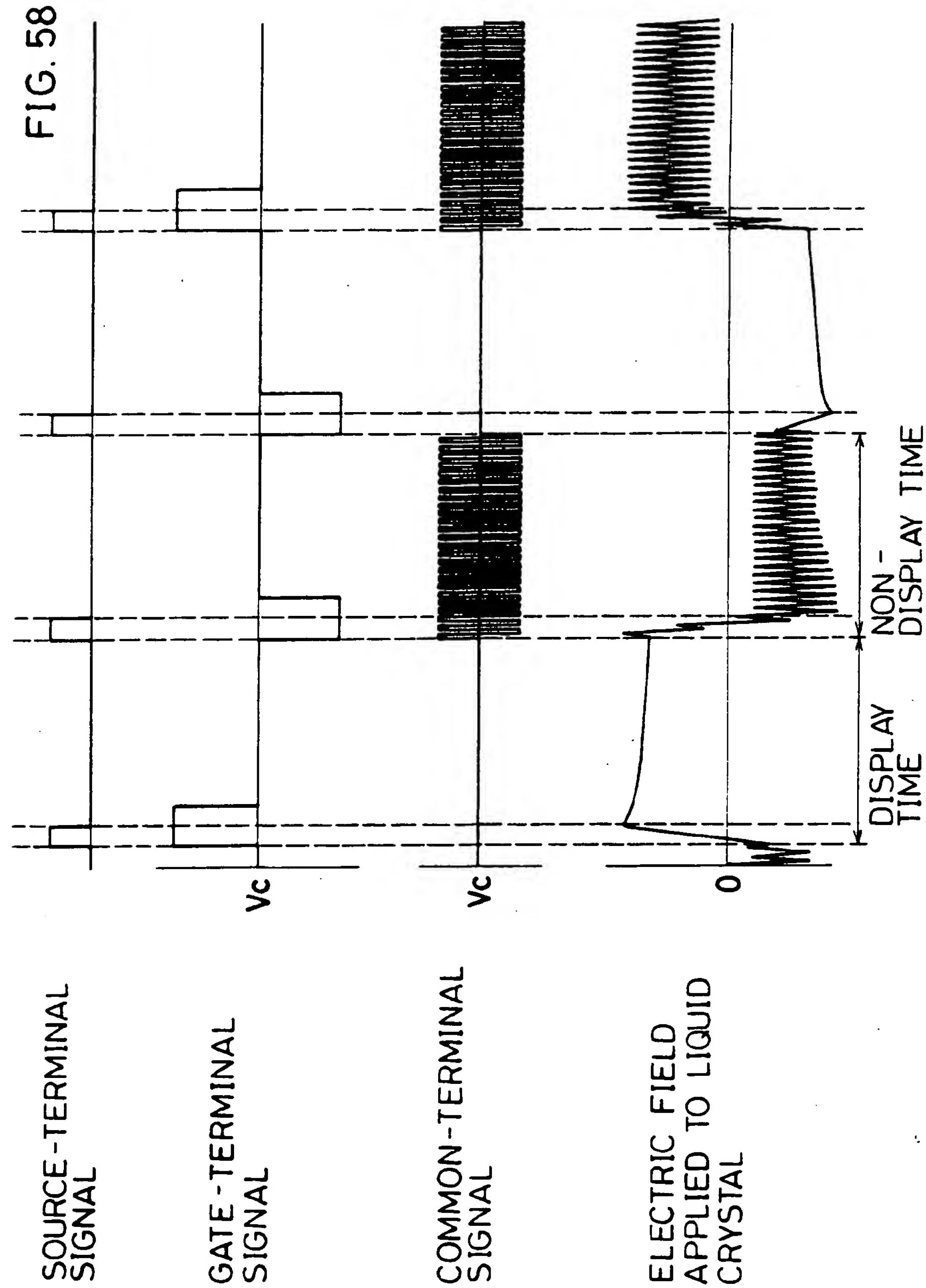


FIG. 58
SOURCE-TERMINAL SIGNAL
GATE-TERMINAL SIGNAL
COMMON-TERMINAL SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
Vc
Vc
0
DISPLAY TIME
NON-DISPLAY TIME

FIG. 59

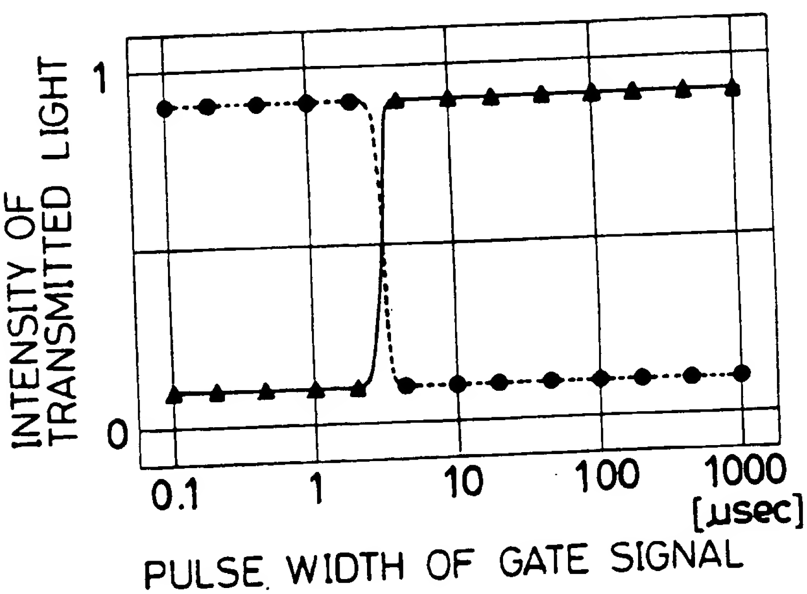

INTENSITY OF
TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[µsec]
PULSE WIDTH OF GATE SIGNAL

FIG. 60

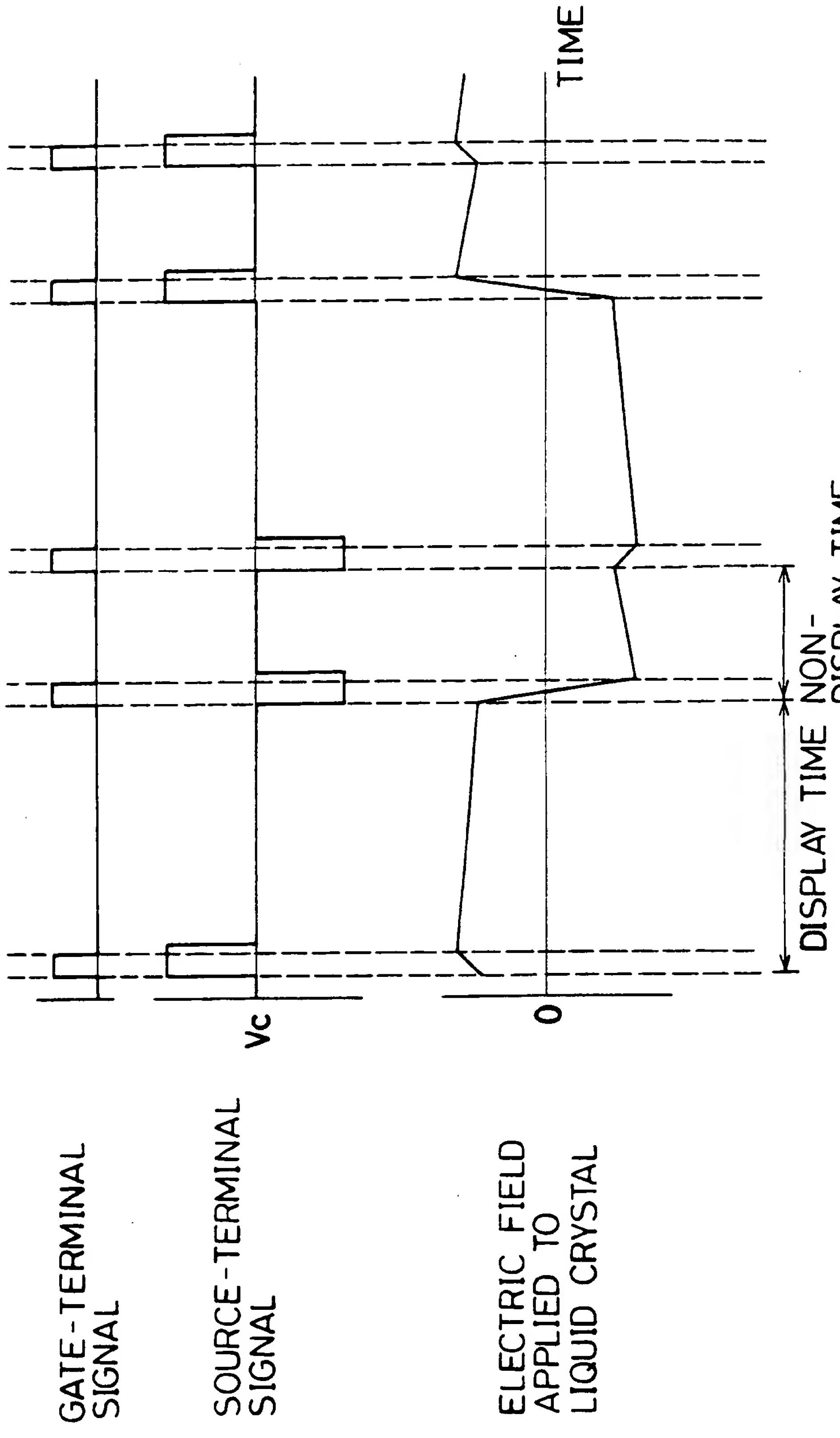
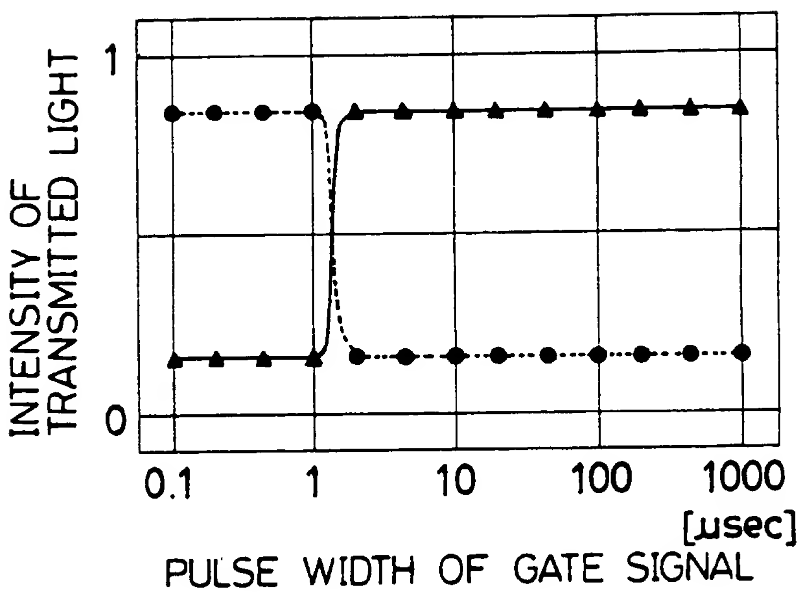

GATE-TERMINAL SIGNAL
SOURCE-TERMINAL SIGNAL
ELECTRIC FIELD APPLIED TO LIQUID CRYSTAL
Vc
0
TIME
DISPLAY TIME
NON-DISPLAY TIME

FIG. 61



INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
PULSE WIDTH OF GATE SIGNAL

FIG. 62

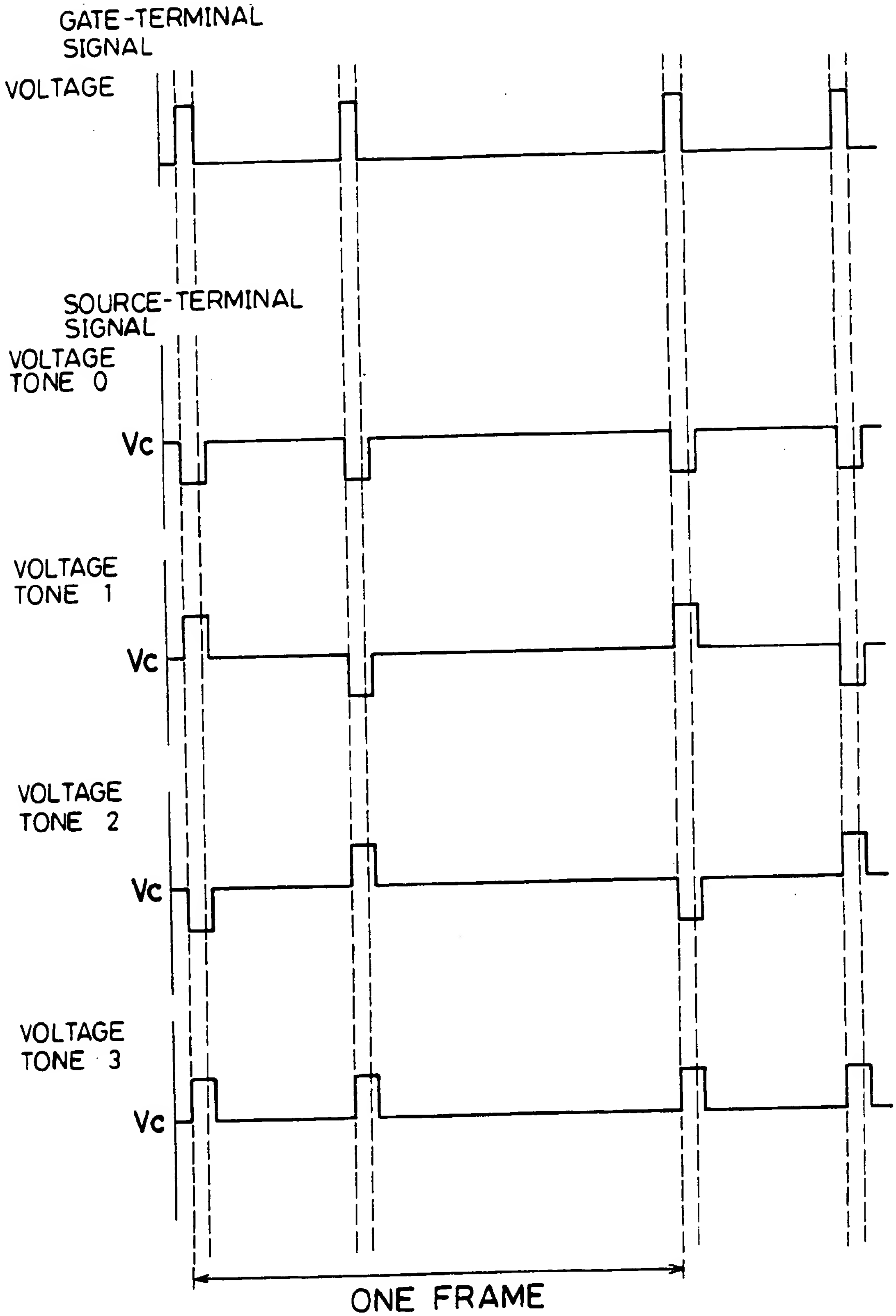
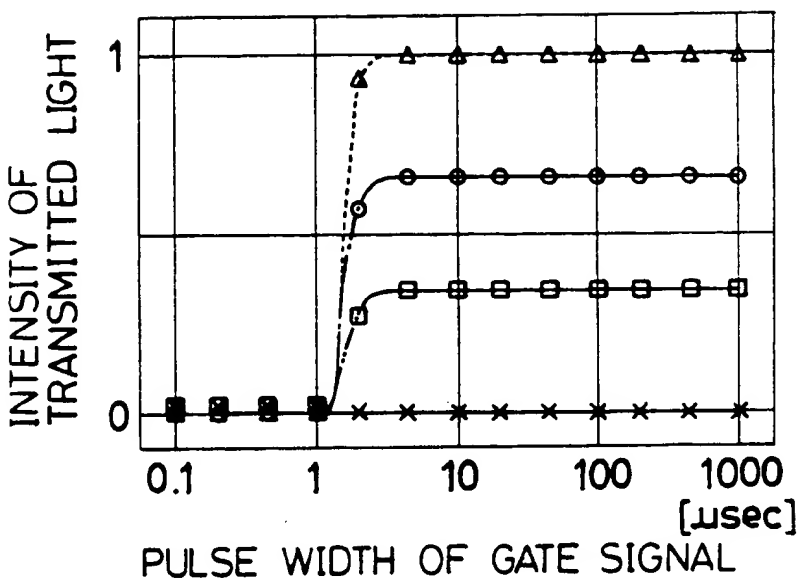

GATE-TERMINAL
SIGNAL
VOLTAGE
SOURCE-TERMINAL
SIGNAL
VOLTAGE
TONE 0
Vc
VOLTAGE
TONE 1
Vc
VOLTAGE
TONE 2
Vc
VOLTAGE
TONE 3
Vc
ONE FRAME

FIG. 63



INTENSITY OF TRANSMITTED LIGHT
1
0
0.1
1
10
100
1000
[μsec]
PULSE WIDTH OF GATE SIGNAL

FIG. 64

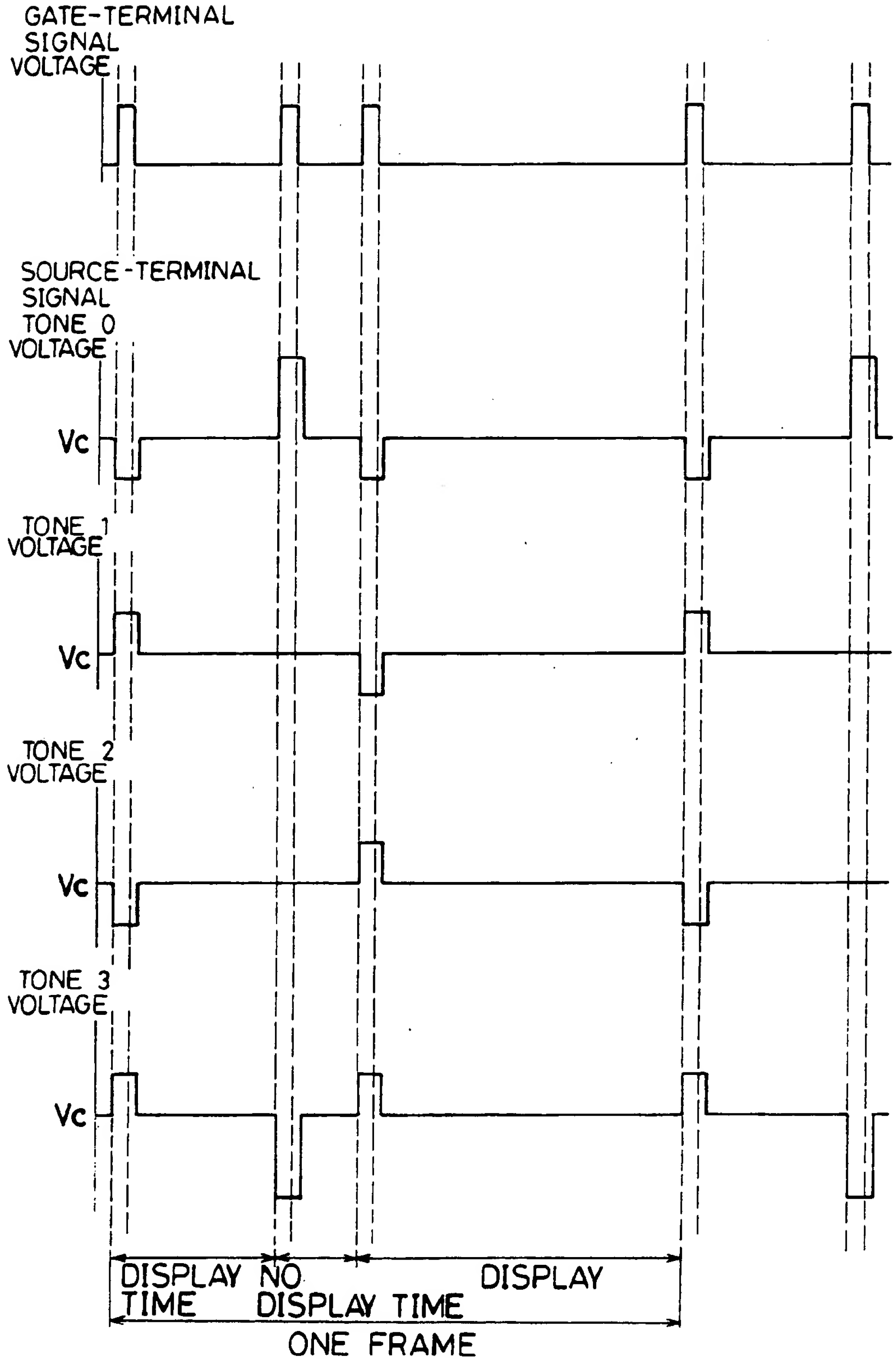

GATE-TERMINAL SIGNAL VOLTAGE
SOURCE-TERMINAL SIGNAL TONE 0 VOLTAGE
Vc
TONE 1 VOLTAGE
Vc
TONE 2 VOLTAGE
Vc
TONE 3 VOLTAGE
Vc
DISPLAY TIME
NO DISPLAY TIME
DISPLAY
ONE FRAME

FIG. 65

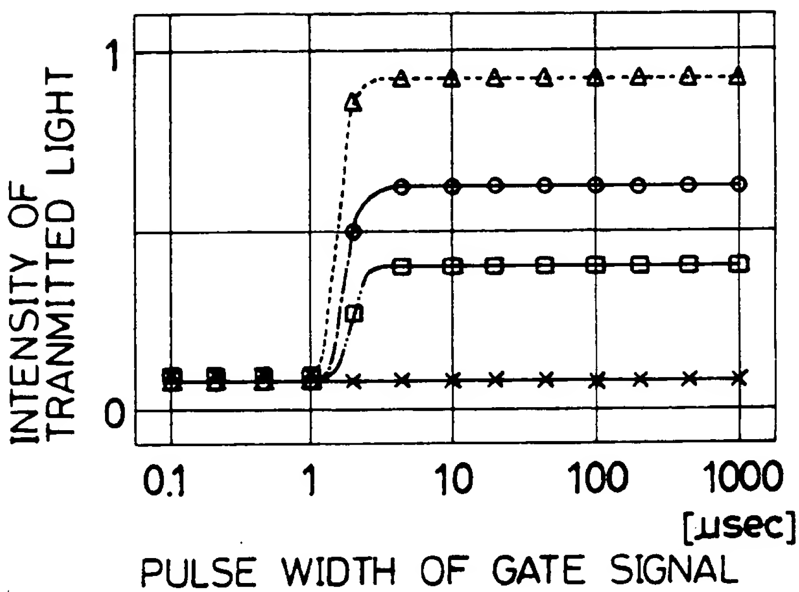
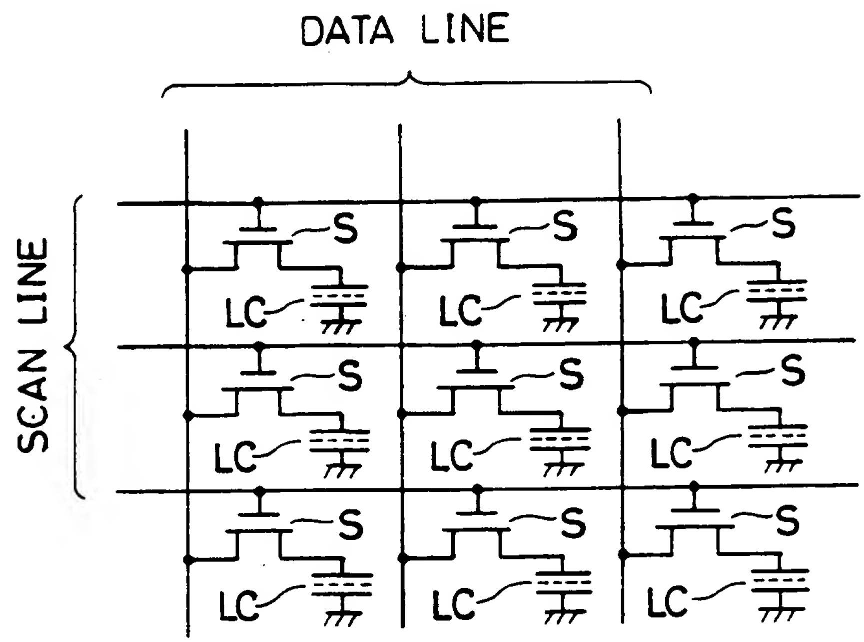
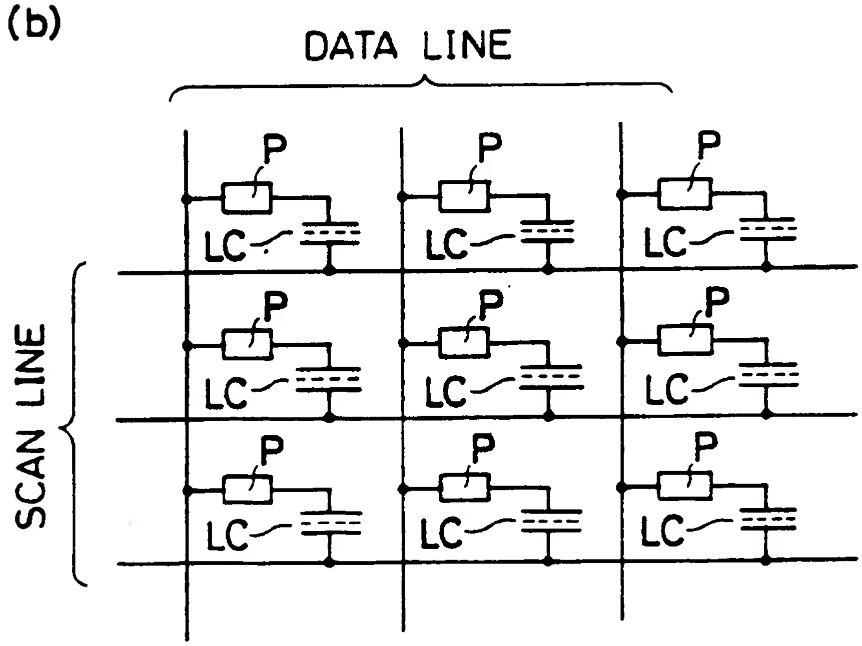

1
0
INTENSITY OF TRANMITTED LIGHT
0.1
1
10
100
1000
[μsec]
PULSE WIDTH OF GATE SIGNAL

FIG. 66

(a)



(b)



European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 93 30 0226

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	EP-A-0 324 997 (PHILIPS) * abstract; figures 3-7 * * column 6, line 32 - column 8, line 32 * ---	1	G09G3/36
A	EP-A-0 433 540 (CANON) * page 9, line 13 - page 10, line 7; figures 12-13 * ---	1	
A	GB-A-2 164 776 (CANON) * abstract; figure 4 * * page 3, line 71 - page 4, line 28 * -----	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

G09G

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	22 MARCH 1993	SAAM C.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
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